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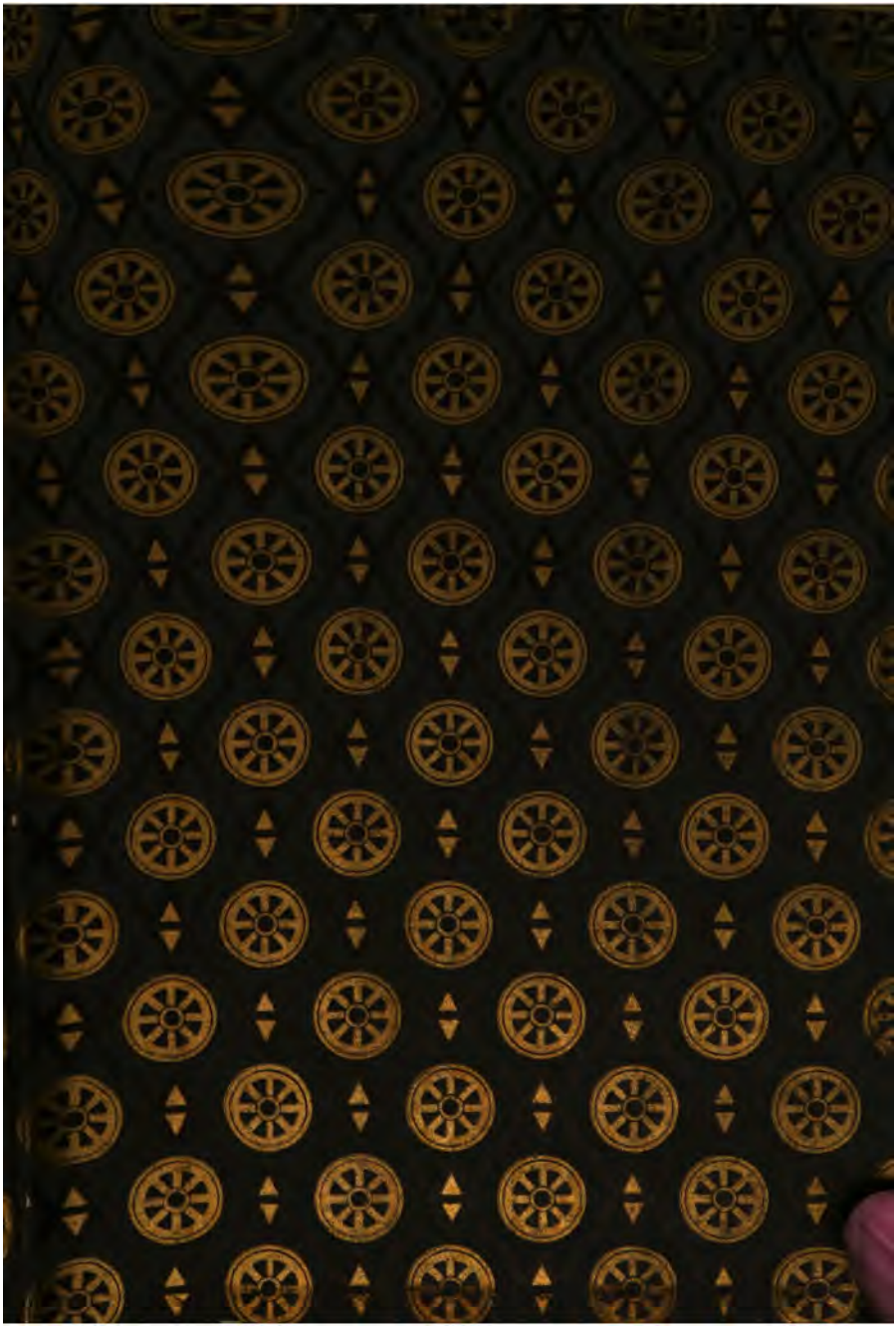

Geo. Westinghouse

Air Brake Tests

Compiled
and
Published by

THE WESTINGHOUSE
AIR BRAKE
COMPANY

In Connection with ITS
EXHIBIT OF BRAKING AP-
PLIANCES *at the* LOUISIANA
PURCHASE EXPOSITION
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THE OLD "DILIGENCE" AND ITS BRAKE.

THE GROWTH OF CAR BRAKING.

ALL development of arts, mechanics and objects of utility have grown out of the necessity for appliances designed to accomplish some particular purpose, and when we look back over the period during which the air brake has developed we are apt to feel somewhat surprised that its inception is so recent, and, in fact, that the whole question of vehicle braking is a comparatively modern one. Knowing that the ancients traveled extensively, and that the great empires of history moved large armies all over the then known world, accompanied by trains of baggage wagons and war machines, it is natural to suppose that the necessity for retarding those vehicles was plainly manifested; but, as a matter of fact, the first suggestion of this necessity by the use of a practical mechanism designed for the purpose does not appear to have been more than 250 years ago. The primitive carts and wagons which were used in agricultural work, and in connection with transportation of baggage and supplies for armies, were of such construction that the natural resistance to rotation of their wheels was quite sufficient to bring them to a stop upon ordinary roads, and in cases of steep grades it was always easy to chain a log or stone to the back of the wagon, so that by dragging it over the ground the speed of the vehicle was checked.

Indeed, to find the time when the question of braking first came into prominence we need go no further back than the period when highways became sufficiently well made and maintained as to admit of a heavy vehicle being drawn over them at comparatively high

speed. Country roads everywhere as late as 1725 were in a most deplorable condition, being narrow and full of ruts and stones. At this time stage coaches had been running for eighty years and more, while the stage wagon — the forerunner of the stage coach — was introduced into England in 1564. During the middle of the 18th century there was considerable agitation for better roads which seemed to have had a beneficial effect, since during the latter part of this century the first mail coaches or "Diligences" were placed upon the roads between London and various cities of Great Britain. These coaches ran at speeds much greater than had been possible before. The one between London and Bristol ran a distance of 117 miles in 15 hours, or an average of about 7¾ miles an hour, which average includes all stops for changing horses, etc., so that the maximum speed must have been considerably in excess of this.

It is a noticeable fact, that with all kinds of conveyances the question of braking has always increased in importance as the demand for higher speeds increased. During the century from 1770 to 1870 there were granted in England about 190 patents for various kinds of braking appliances for common-road vehicles; of these 46 were applied to the periphery of the wheel; 28 on the nave; 27 were actuated by the movement of the horses; 21 were applied to fly or brake wheels; 8 were applied to the axle; 10 were actuated by a spring; 4 were automatic; 3 electromagnetic; 3 pneumatic; 4 relying on momentum; 3 accumulated power for subsequent propulsion, etc. In America there had been 170 such patents, 21 of which were for automatic designs.

In connection with common road vehicles it is worthy to note that the first devices adopted are those which have formed the basis of almost all brake appliances which have since been employed for the same kind of vehicle. The early stage coaches and even the later mail coaches were provided with an iron shoe which slips under the wheel and is chained to the forepart of the coach so as to drag both shoe and wheel along over the surface of the ground. This method of braking was one of the first devices adopted and is used extensively

THE GROWTH OF CAR BRAKING

to-day. The old arrangement of two brake blocks and a beam with suitable levers connecting each to the driver was also early introduced, and all kinds of developments from this arrangement are seen to-day on various kinds of vehicles.

The many patents granted referring to this subject clearly shows how important the question of braking had already become, and it is impossible to tell what the common-road vehicle of to-day would have been if the power of steam had not been discovered right in the midst of the great development of roads and road vehicles and turned the attention of inventors to channels which were destined to entirely change the relative importance of earlier modes of travel.

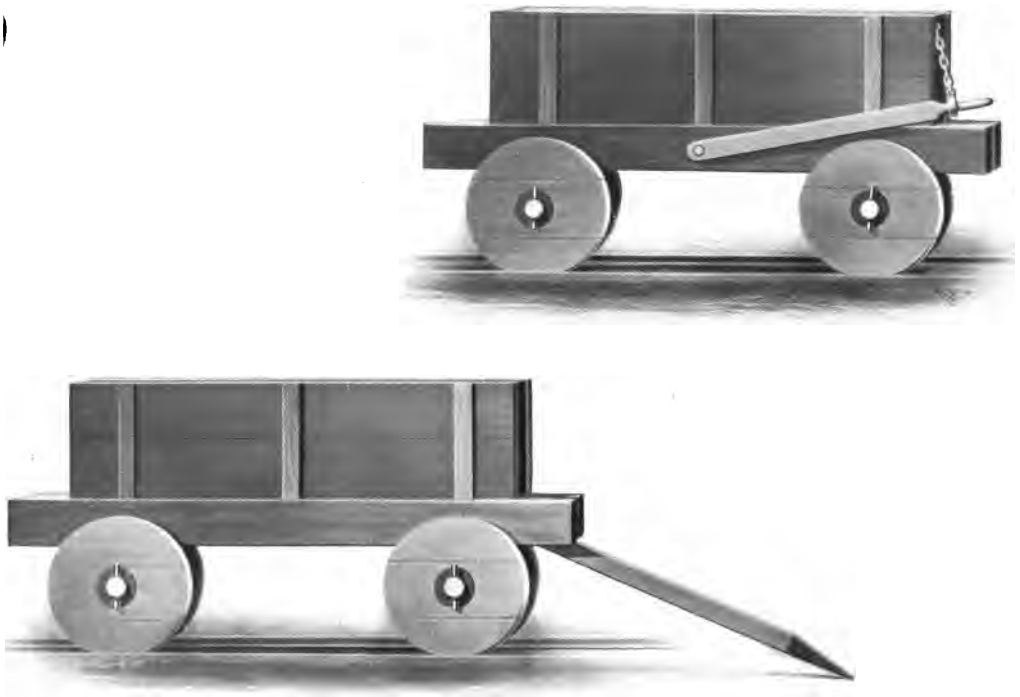
The railroad was no new thing, even at this time, for so far back as 1630 an enterprising mine owner at Newcastle-on-Tyne, finding the roads between his mines and the river so bad as to seriously interfere with the hauling of coal, conceived the idea of laying in the road wooden rails and running thereon cars with wooden wheels. The tractive effort of these cars was so much decreased that the necessity of some contrivance to check their speed was at once apparent and brought out simple forms of brakes. One of these forms consisted of a metal tipped beam which was fastened to the frame of the car in such a way as to scrape along in the ground at the side of the track. Another form was a simple lever pivoted to the side near the center of the car and ordinarily held up by a chain, which, when desired for use, could be liberated and pressed by hand or foot against the top periphery of the wheel.

There were many other simple devices adopted by the primitive railroads, such as the "Sprag" brake, which was applied to cars of later construction when the wheels were made with spokes and the iron flange tire was applied. The so-called "Sprag" was a hardwood stick which was thrust through the wheel underneath the frame of the car, thus causing the former to skid along upon the rail.

Many other primitive forms of brakes were applied to such railroads as existed, but the speeds employed on these roads were generally low and the cars small enough to be drawn by draught animals, and the question

was not a particularly serious one until the advent of the steam locomotive. The great revolution which the knowledge of the power and use of steam has brought about was well under way during the first part of the nineteenth century. During the first 70 years of the century about 650 patents were granted in England for various kinds of brakes for railroad service. Of these 21 were for electro-magnetic brakes; 20 hydrostatic; 32 pneumatic; 50 steam, and the balance were for various other kinds, mostly hand brakes and different designs of the foundation brake gear. In 1833, Stevenson patented his steam brake, consisting simply of a small cylinder containing a piston, the rod of which connected through a system of levers to a cam brake. The first pneumatic brake was a vacuum brake patented by James Nasmyth and Charles May in 1844. In 1848 Samuel C. Lister patented an air brake having an axle-driven pump and suitable reservoir to be placed on the "Guard's Carriage," and suitable cylinder, pipe, and connections on the various cars to constitute a straight-air equipment, quite the same as that which followed many years after, except that it was designed to be operated by the guard and not by the engineer.

Many interesting and ingenious contrivances were suggested and patents obtained for same. In the United States up to 1870 there had been granted 305 patents for railway brakes, of which 8 were automatic, 3 electro-magnetic, 5 steam, 1 vacuum, and 2 air brakes, the balance referring to various forms of foundation brake gear and other devices which have never stood the test of actual practice. Some of the various systems originating in this country were extensively tried and seemed to meet the conditions for which they were designed with various grades of success. The "Cramer" brake, which was brought into use in 1853, consisted of a large spiral spring attached to the brake staff at the end of the car and which was wound up by the brakeman immediately after leaving a station. Attached to the mechanism was a cord which ran through the train to the engineer's cab and the brake was so designed that when the engineer pulled the cord coil springs on each vehicle were released and these at once wound up



PRIMITIVE FORMS OF CAR BRAKES.

chains leading to the foundation brake gear, thereby bringing the brake shoes against the wheels.

The "Loughridge Chain Brake," which came into use in 1855, consisted of a system of rods and chains continuously connected throughout the train, as follows: On each vehicle were two pairs of small pulleys, each pair sliding toward the other upon an iron framework, but held apart by a spring; to each pair was connected a top rod leading to the foundation brake gear. Upon the engine was placed a drum connected by a worm and gear to a small friction wheel; when a lever in the engineer's cab was pulled this friction wheel was brought into contact with the periphery of one of the driving wheels, thereby causing the drum to wind up the chain and shorten its length throughout the train; in so doing the pulleys upon each vehicle were brought closer together, thereby applying the brakes.

Of course, the earlier type of hand brake underwent considerable improvement as the years went on and as experience made it advisable and necessary. For many years during the early railroading the majority of passenger and all freight equipment cars were braked by hand; nevertheless there was a constant desire for and search after a practical automatic brake. These types just referred to were the result of much research; there were many other forms of brake which attained a certain degree of prominence and were more or less successfully operated upon different roads throughout the country. We shall have occasion to mention some of these in connection with tests given later on.

In 1869, the Westinghouse non-automatic air brake, which has since generally been designated as the "Straight Air" brake, was brought out. It consisted of a very simple steam-actuated air pump placed upon the side of the engine, and a reservoir in which the compressed air could be stored. A pipe line from the reservoir was carried throughout the length of the train, connections between vehicles being made by means of hose and couplings. Each vehicle was provided with a simple cast-iron cylinder, the piston rod of which was connected to the brake rigging in such a way that when the air was admitted to the cylinder

the piston was forced out and the brakes thereby applied. In the engineer's cab there was placed in the pipe line just mentioned a three-way cock, by means of which compressed air could be admitted to the trainpipe and thus to the cylinders on each car; or the air already in the cylinders and trainpipe could be discharged to the atmosphere, thus releasing the brakes. This was the simplest and most efficient brake that had been introduced up to that time and was largely adopted by the American railways; but while all that could be desired for single vehicles, the danger incident to the entire loss of braking power when most needed, due to the bursting of hose under pressure, the parting of the train or other rupture of the brake system led to the invention of the automatic brake by Mr. George Westinghouse, probably the greatest advance step ever made in the development of the art. The first form of this brake was introduced in 1872, and is now generally referred to as the "plain automatic." The essential difference between this brake and the straight-air type which it promptly superseded consisted in the installation of supplementary or auxiliary reservoirs for the storage of compressed air on the cars in addition to the main reservoir on the locomotive, so that each vehicle carried its own supply, and the employment of a most ingenious valve mechanism by means of which the application of the brake was caused by the reduction of air pressure in the trainpipe, whether such reduction was made intentionally or as the result of accident. The device by means of which this arrangement was made possible was called a "triple valve," because of its three-fold function of applying the brake, releasing it, and recharging the auxiliary reservoir. In this triple valve was a slide valve attached to a piston, so placed that trainpipe pressure was always on one side of it and auxiliary reservoir pressure on the other. When trainpipe pressure exceeded auxiliary reservoir pressure the piston and slide valve took such position that air could flow from the trainpipe into the auxiliary reservoir, at the same time opening a port leading from the brake cylinder to the atmosphere; if the trainpipe pressure was reduced below that of the auxiliary reservoir, the piston and slide valve moved to another position in which air could flow from the auxiliary

reservoir into the brake cylinder and apply the brakes. The operation of the brakes throughout the train was thus under the entire control of the engineer through the medium of trainpipe pressure actuating the triple valve on each vehicle. A reduction of trainpipe pressure applied the brakes, while the restoration of normal pressure by allowing air to flow from the main reservoir into the trainpipe released them.

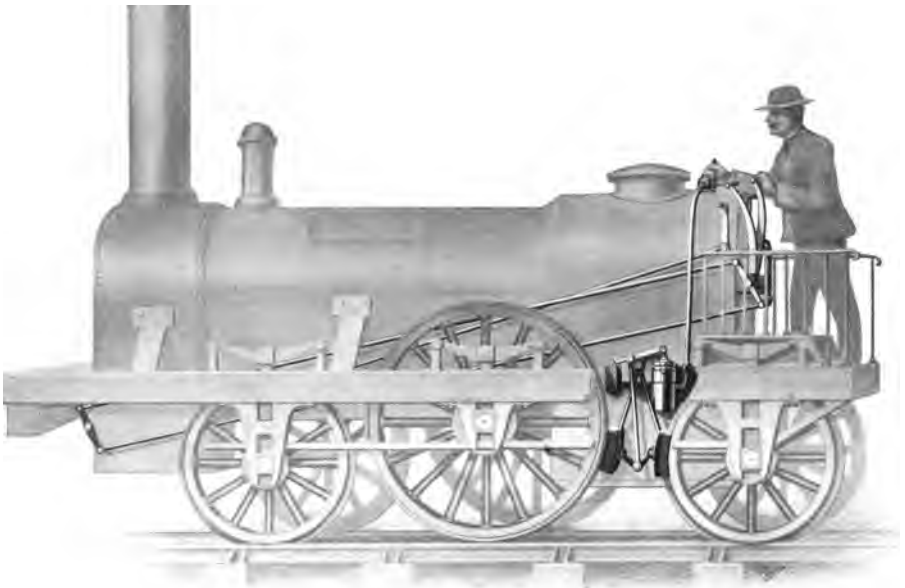
The three-way cock in the engineer's cab was replaced by a more elaborate valve known as an engineer's brake valve. The necessity for this substitution was due to the fact that in applying the brakes the reduction of pressure in the trainpipe had to be more carefully made than was practicable with an ordinary three-way cock. This brake valve was arranged so that in releasing the brakes, air was allowed to flow from the main reservoir on the engine into the trainpipe and auxiliary reservoirs. The engineer by moving the handle to the application position connected the trainpipe to the atmosphere through very carefully graduated openings and the pressure gauge connected to the trainpipe showed how much reduction was made, and indicated, therefore, the amount of air that would flow from the auxiliary reservoirs into the brake cylinders. As the discharge to the atmosphere from the trainpipe was slow, the pressure of the latter decreased throughout its entire length almost uniformally, and, as a consequence, the brakes were applied throughout the train with practically equal force and in about the same time. Thus the difficulty with straight air was overcome and the new conditions then existing were fully met.

In the same year, 1872, the Smith vacuum brake appeared. This apparatus consisted of two collapsible cylinders on each vehicle, connected with two lines of trainpipe running throughout the train and connected between vehicles as in the compressed air brake. An "ejector" was installed on the locomotive, by means of which the air in the trainpipes and brake cylinders was exhausted and the brakes applied through the contraction of the cylinders with which the brake levers were connected. The greater safety and efficiency of the auto-

matic air brake was demonstrated so early that with a very few exceptions the plain vacuum brake soon passed out of service in the United States. For the same reasons the automatic vacuum, a later invention, was never adopted to any extent outside of England.

The immense advantage to railway companies along the line of higher speed, greater safety, and pronounced economy in the substitution of a reliable automatic power brake under the control of the engineer for the old hand brake was soon recognized and the work of making this change proceeded rapidly throughout the entire country. Naturally enough, the new conditions encountered brought to light new problems, the solution of which enlisted the best efforts of railway officials and brake manufacturers alike. In many instances it was found that the only possible way to determine the questions involved with any degree of satisfaction was by means of practical tests made under such conditions as are found in actual service.

It is the primary purpose of this publication to present in a comprehensive way, and at the same time in condensed form, the data that has resulted from the most significant and valuable of these tests, with such comment as the wider experience of the day seems to justify.



THE STEVENSON STEAM LOCOMOTIVE BRAKE.

GALTON-WESTINGHOUSE TESTS.

AMONG the first and most important experiments of the character indicated were those made in England in 1878-1879 by Captain Douglas Galton and Mr. George Westinghouse, which had for their object the determination of the coefficient of friction between brake shoes and wheels and between wheels and rails, including the variation of this coefficient for different speeds and throughout different durations of brake application. The reports of these tests were made to the Institution of Mechanical Engineers of London in three papers, which are reproduced in the following pages with only such changes in the number of the illustrations as are unavoidable. In reprinting this most interesting contribution to the history of the development of power brakes for railway trains, the attention of the reader is called to the fact that the principles established by these tests made twenty-five years ago have never been superseded, but apply with equal force to present-day conditions.

A short time previous to these experiments, a paper relating to brakes was read before the Institution of Mechanical Engineers, and during the discussion of this paper, Mr. Westinghouse called attention to the fact that, in testing the action of various kinds of brake shoes, he had observed a very marked difference in the friction of the shoes upon the wheels at high speeds and at low speeds. He believed that a determination of the facts was of great importance and volunteered to design and construct the necessary automatic recording apparatus and to carry out a system of experiments under the direction of any person who should be appointed by the President of the Society to supervise the tests and report to the Society. The Society immediately took advantage of this offer of Mr. Westinghouse and designated Captain Douglas Galton, who, on behalf of the Society, personally directed the experiments. The success of the project became assured when the London, Brighton & South Coast Railway placed a locomotive and brake van at the disposal of Captain Galton and Mr. Westinghouse, and offered every facility for conducting the experiments; to

GALTON-WESTINGHOUSE TESTS

the great interest manifested by this railway, the valuable information secured from these experiments is largely due.

It is not a little interesting to observe that the results obtained in these experiments, which were the first investigations of this character to be carried out upon any practical scale, may be considered among the most reliable data in existence upon this subject; furthermore, subsequent investigations have tended to confirm the general character of the results, if not the entire accuracy of the data, thus presented.

ON THE EFFECT OF BRAKES UPON RAILWAY TRAINS.

By Captain DOUGLAS GALTON, C. B., Hon. D.C.L., F.R.S.

The following paper is an account of experiments upon the coefficient of friction between the brake-blocks and the wheels, and between the wheels and the rails, at different velocities, both when the wheels are revolving and when skidded.

These experiments form the first instalment of a series which it is intended to make, in order to ascertain, 1st, the actual pressure which it is necessary to exert on the wheels of a train in order to produce a maximum retardation at different velocities; 2d, the actual pressure exerted on the wheels with the several kinds of continuous brakes now in use; 3d, the time required to bring the brake-blocks into operation in different parts of a train with the several kinds of continuous brakes; 4th, the retarding power of the different kinds of continuous brakes now in use on trains under similar conditions of equal weight and when running at the same speed.

This paper includes the first series of experiments only.

The author was enabled to make this series through the courtesy of the London, Brighton & South Coast Railway Company, and of their locomotive superintendent, Mr. Stroudley, who provided a van and other facilities for making the experiments; and through the courtesy and assistance of Mr. Westinghouse, by whom the recording apparatus was designed. The author was assisted in making the experiments, and in their reduction, by Mr. Horace Darwin.

The experiments described in this paper were made on the Brighton Railway, with a special van constructed for the purpose; it was attached to an engine, and was run at various speeds, during which time various forces were measured by self-recording dynamometers. The principle of these dynamometers is that the force to be measured acts on a piston fitting in a cylinder full of water, and the pressure of the water is measured by a Richards indicator connected by a pipe to the cylinder; thus, as the drum of the indicator revolves, diagrams

are obtained giving the force acting on the piston. The advantages of this method are obvious, as the indicator can be placed at any convenient point, and the inertia of the water tends to make the pencil keep a position corresponding to the mean force.

Fig. 1. **Plan.**

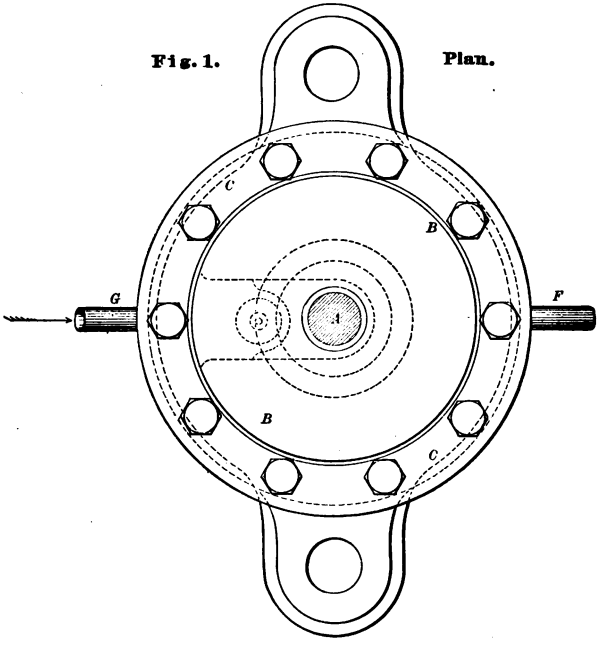
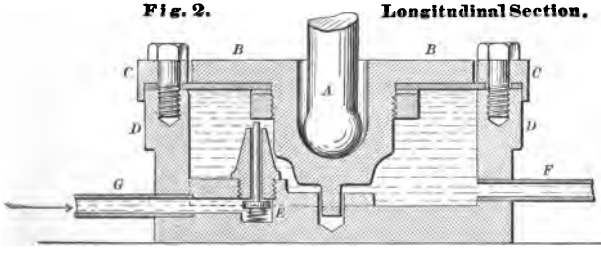
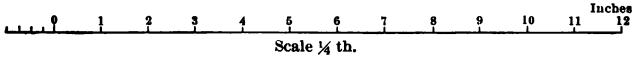


Fig. 2. **Longitudinal Section.**





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Construction of Dynamometers.

Air Brake Tests

GALTON-WESTINGHOUSE TESTS

The construction of the dynamometers is represented in Figs. 1 and 2. Each consists of a piston, and what answers to the cylinder, but would be better described as a cylindrical box with a ring fastened upon its upper edge. A is the rod by which the thrust to be measured is transmitted to the piston B. This piston merely consists of a cast-iron disc, having on one side a central cavity in which rests the rounded end of the rod A, and on the other side a central projection which acts as a guide. The ring C, resting on the edge of the cylindrical box D and bolted to it, is of the same thickness as the piston, which fits within it, the ring and piston thus forming a cover to the box D. The piston fits so as to slide easily within the ring, with but little friction; and is made water-tight by placing below it a disc of india-rubber, which is fastened to the centre of the piston by a brass collar, and has its outer edge clamped in between the ring and the edge of the cylindrical box D. The dynamometer has thus a perfectly water-tight piston, which will move with very little friction; and as its movement is very small, the disturbing effect of the india-rubber at its edge may be neglected; consequently the forces acting on the piston through the rod A will be registered by the indicator by means of the pressure of the water. F is the pipe leading to the indicator. We will neglect the valve E for the present, and explain its use a little further on. Supposing the whole apparatus to be filled with water, and that a force were applied to the piston by the rod A, it would force some of the water out of the box D, through the pipe F, into the indicator cylinder. The area of the indicator piston is 0.5 square inch, and its maximum range 0.8 inch, therefore the quantity of water required to make a maximum movement of the pencil is 0.4 cubic inch; and as the area of the piston B is 30 square inches, its movement would only be 0.013 or $\frac{1}{75}$ inch; which is such a small movement that the india-rubber will introduce no appreciable error.

If the indicator piston did not leak, and if it were possible to keep exactly the right quantity of water in the apparatus, nothing more would be required to make it work properly; but as this is evidently impossible, the self-acting supply valve E, opening outwards, becomes

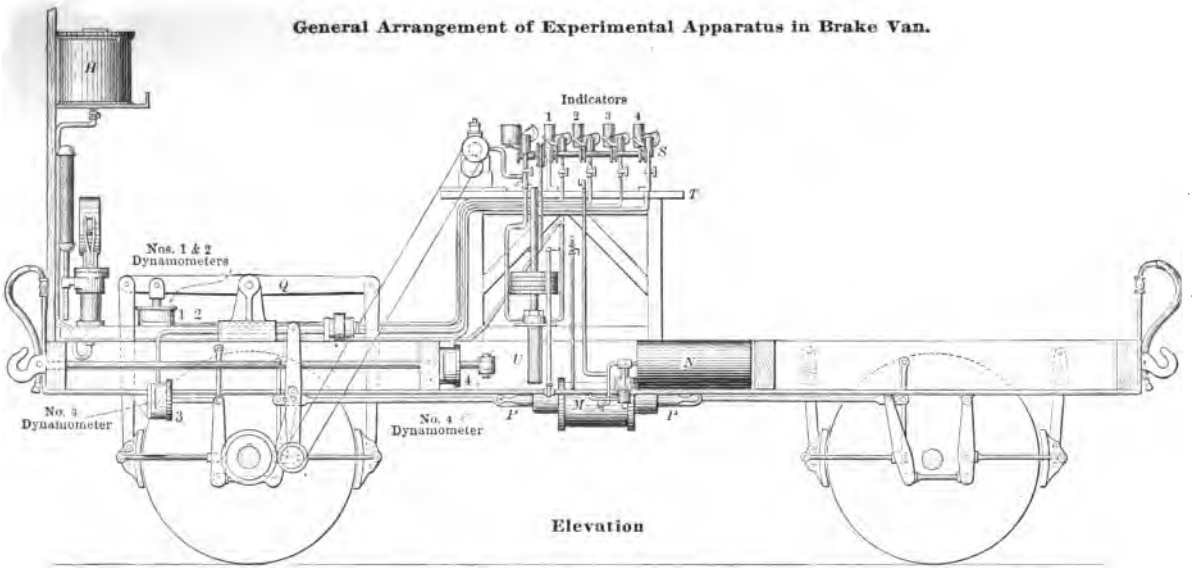
necessary. A small pipe G leads from an accumulator H, Fig. 3, which is loaded to a greater pressure than can ever arise in the box D; the excess of pressure from the accumulator tends to close the valve E; and there is also a spring which forces the valve on to its seat. The valve is seated with india-rubber, and is made perfectly water-tight; its spindle passes up so as very nearly to touch the brass collar on the inner side of the piston. Suppose the whole apparatus to be filled with water when there is no force acting on the piston; then if a sufficient force is applied by the rod A, this will move the piston inwards so as to send some water into the indicator, and raise the pencil, and will also open the valve E; and, as the pressure in the accumulator is in excess of that in the box D, water will enter the box, and will go on entering till the piston is raised again so as no longer to open the valve. Now, if the force on the piston be removed, the indicator spring will force the quantity of water received, which is less than 0.4 cubic inch, back into the box D, and will thereby raise the piston, but through a space less than $\frac{1}{715}$ inch; and thus the piston will never move more than $\frac{1}{715}$ inch above the position in which it touched the valve E. But if a smaller force be applied to the piston, as in practice, it will not be pushed in so far, unless sufficient leakage has meantime taken place; in that case the piston will move inwards through its full distance, and will then open the valve. Thus the valve always keeps the right quantity of water in the apparatus to make it work properly, by occasionally opening and letting in enough water to make up for leakage.

In Figs. 3 and 4 is shown in elevation and plan the general arrangement of the apparatus in the special brake-van built by the London, Brighton & South Coast Railway Company for these experiments. To this van the Westinghouse automatic brake was applied, having four dynamometers attached to it, like the one described. The dynamometers Nos. 1 and 2, situated as shown in Figs. 3 and 4, measure the retarding force which the friction of the brake-blocks exerts on the wheels; No. 3 measures the force with which the blocks press against the wheels; No. 4, the force required

Fig. 3

GALTON-WESTINGHOUSE TESTS.

General Arrangement of Experimental Apparatus in Brake Van.



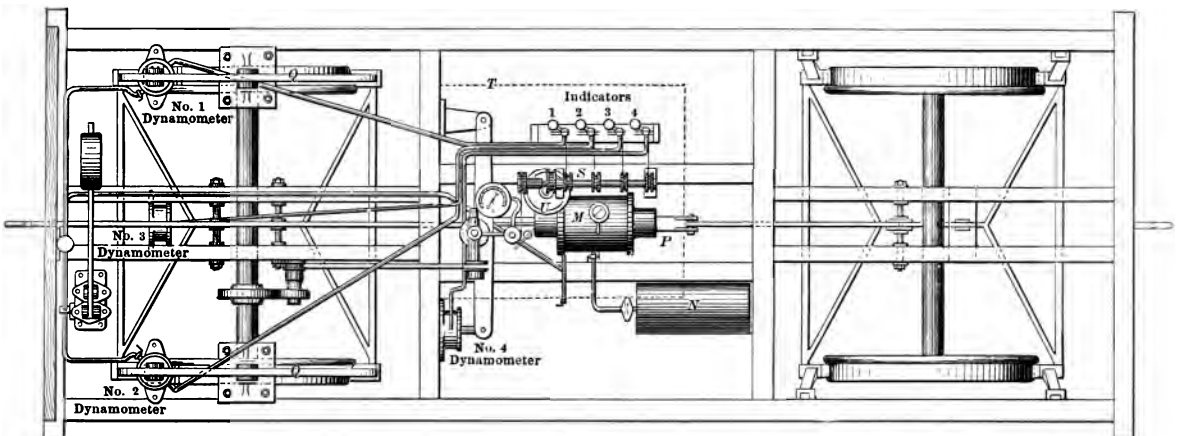
to drag the van. The arrangement of the levers for applying the brake is not the same as that used on the ordinary rolling stock of the Brighton Railway, but has been slightly modified by Mr. Westinghouse in order to make the pressure equal on both sides of the wheels, and to provide for the application of the dynamometers. M is the cylinder belonging to the Westinghouse brake apparatus; into this the compressed air flows from the reservoir N when the brake is applied, and forces the two pistons apart, thus moving the two rods P P outwards, and by means of the levers pressing the brake-blocks against the wheels. It is evident from the arrangement here shown that the pressure must be equal on each side of the wheels; and that the pressure on dynamometer No. 3 must be equal to the thrust on the rod P, and hence proportional to the pressure on the wheels. The lever Q, pivoted at its center, will evidently tend to turn with a moment equal to the retarding moment exerted by the friction of the brake-blocks on the wheels; and hence dynamometers Nos. 1 and 2 will register forces proportional to this moment. The brake could be applied to all the wheels of the van, but during the experiments it was only applied to the pair of wheels to the levers of which the dynamometers Nos. 1, 2, and 3 were attached. Dynamometer No. 4 is connected to the drawbar by a lever, as shown in the plan, Fig. 4, and thus registers the force required to draw the van. A self-recording speed-indicator was used, designed by Mr. Westinghouse. This instrument has been repeatedly tested, and was used at the brake trials on the North British Railway, and on the German State Railway. It consists of a small dynamometer made on the same principle as that just described; it measures the centrifugal force of two weights, which are made to revolve by a strap from a pulley on a shaft driven by friction-gear from the pair of wheels to which the brake was applied; a Richards indicator is used, as with the other dynamometers. As the centrifugal force varies as the square of the velocity, the speed is got by taking the square root of the ordinate at any point of the indicator diagram.

The diagrams from the speed indicator show the speed of the pair of

GALTON-WESTINGHOUSE TESTS.

General Arrangement of Experimental Apparatus in Brake Van.

Fig. 4



Plan

Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 Feet

Scale 1/39 th

wheels to which the brake was applied, and therefore the velocity of the train at the moment of applying the brake and subsequently, provided there is no slipping. Any variation in the speed diagram is due to the wheels slipping, and shows to what extent and in what way the brake stops the wheels. Two of Mr. Stroudley's speed indicators were fixed side by side in the van; one attached to the axle belonging to the braked wheels, the other to the axle which was running free. The difference of these indicators showed if slipping took place. They did not record any diagrams, but were read by means of a Bourdon gauge attached to them, with the face divided in such a way that the hand shows the speed in miles per hour. A similar gauge was attached, for convenience, to the Westinghouse speed indicator described above.

The indicators were all placed on a table T in the center of the van, as shown in Figs. 3 and 4; and their drums were made to revolve by the cords being wound up on pulleys on the shaft S, which is turned at a uniform rate by a water clock U. This clock merely consists of a plunger sliding in a cylinder through a water-tight packing, and loaded with a heavy weight; it is wound up by connecting it with the accumulator H, and at the beginning of each experiment a small cock is opened, which allows the water to run out and the weight to fall, thereby turning the indicators round at an ascertained uniform speed. Thus while the ordinates of the diagrams taken from these several indicators show the various forces, the abscissæ show the time occupied in the experiments.

In these experiments the tires were of steel, and the brake-blocks of cast-iron.

The difficulties attendant upon the preparation and adjustment of this delicate apparatus consumed so much more time than had been anticipated, that it was only on the 27th, 28th, and 29th of May that a series of experiments could be made. These took place in the vicinity of Brighton. The first day was dry; the second stormy; the third fine, with showers.

Numerous diagrams were taken by the apparatus, which have re-

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quired very careful reduction. Unfortunately the date at which it was necessary to send in the paper to the Institution has not afforded time for a complete collation of the results; the author therefore submits this as a preliminary paper; and limits himself to exhibiting in Figs. 5 to 13 a few of the indicator diagrams which were taken, and which illustrate the more striking results.

In these diagrams, the line P P represents the Pressure applied to the brake-blocks in lbs.; its ordinates multiplied by 240 give the total pressure in lbs., collectively exerted upon the four brake-blocks of the braked pair of wheels. The line F^1 F^1 represents the corresponding Friction between the brake-blocks and the wheels, as measured by dynamometer No. 1; its ordinates multiplied by 45 give the total friction in lbs., collectively produced between the two brake-blocks, to which No. 1 was attached, and the wheel. The line F^2 F^2 represents the same for dynamometer No. 2. The line T T represents the Traction upon the draw-bar in lbs.; its ordinates multiplied by 60 give the absolute strain upon the draw-bar in lbs. The line S S represents the linear speed of the circumference of the braked wheels in miles per hour, which, when there is no slipping, is equal to the velocity of the train. The length of each diagram shows the duration of the experiments in seconds, according to the scale marked along the base line.

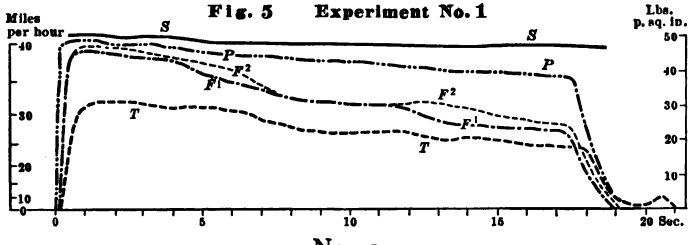
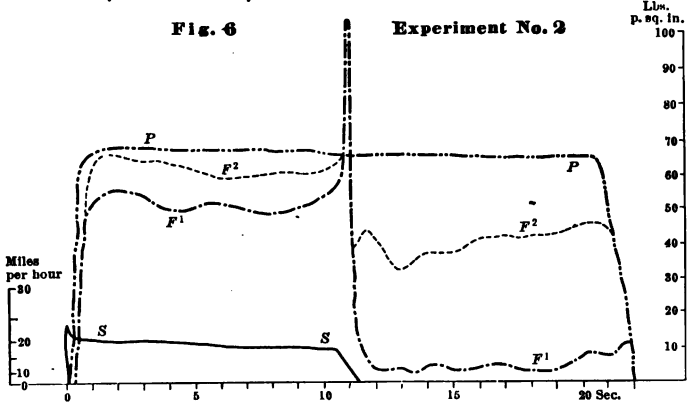


Fig. 5. (Exp. 1. 29th May.) — In this case the speed remained nearly constant, varying from 41 miles per hour at the beginning to 40 miles per hour at the end.

The compressed air was allowed to escape from the brake-cylinder through a small aperture, and thus the pressure between the blocks and the wheels diminished, as shown by line P P.

The line F F shows that the friction between the brake-blocks and the wheels diminished more rapidly than the pressure.

The speed indicated by the rotation of the wheels to which the brakes were applied was the same as that of the wheels running free: as shown by the Stroudley indicators.



No. 2.

Fig. 6. (Exp. 11. 27th May.)—This experiment was commenced when the van was moving at a speed of 25 miles an hour. The application of the brake slackened the speed to 20 miles an hour in ten seconds, when the wheels skidded, as shown by line S S; and the experiment terminated in 22 seconds, when the speed had been reduced to 17 miles an hour.

In this case the line S S shows no diminution in the speed of rotation of the wheels below the speed due to the velocity of the train, until the skidding took place. In the 10 seconds which elapsed from the time when the brakes were fully on till the wheels skidded, the speed of the train was reduced from 25 to 20 miles an hour, as shown by the line S S; whereas in the period of 11 seconds which elapsed

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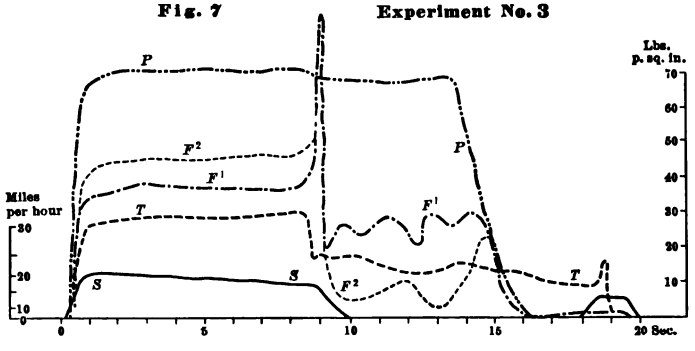
between the skidding of the wheels and the cessation of the experiment the train's velocity was only reduced from 20 miles to 17 miles per hour, as shown by the Stroudley indicators. The skidding was only momentary, the wheels beginning to revolve again almost instantly; but the grip of the brake-blocks was then almost entirely on one wheel, as shown by the wide divergence between the lines F¹ F¹ and F² F²; even in the case of the higher line the friction was much less than before the skidding; so that the total retarding effect on the train was greatly diminished.

Fig. 7 **Experiment No. 3**



No. 3.

Fig. 7. (Exp. 24. 28th May.)—In this experiment the velocity of the train was 21 miles an hour when the brakes were applied to the wheels, and was reduced by the action of the brakes to 18 miles, when the wheels immediately skidded.

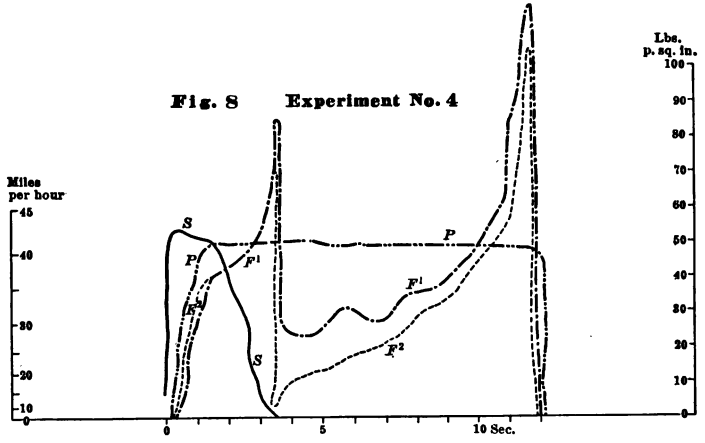
The line F F shows that the coefficient of friction between the brake-blocks and the wheels gradually increased as the speed diminished, until the skidding point was reached; and line T T shows that the tractive force exerted on the draw-bar was suddenly greatly diminished after the skidding took place.

No. 4.

Fig. 8. (Exp. 15. 28th May.)—In this case the brake-van was detached from the engine by means of a slip coupling, when traveling at a speed of 40 miles an hour. The pressure of air in the brake-cylinder,

and consequently the pressure on the brake-blocks, remained nearly constant during the experiment, as shown by line P P.

The pressure being greater than that required by the coefficient of friction between the brake-blocks and wheels corresponding to the



velocity, the friction increased so rapidly as to cause the wheels to skid immediately, as shown by the line S S.

After the skidding, the friction at once increased rapidly, as shown by F F; but rose again as the train's velocity diminished, and attained its maximum when the train came to rest, which occurred in many jerks in 12½ seconds.

No. 5.

Fig. 9. (Exp. 16. 28th May.)—In this case also the brake-van was detached from the engine by means of a slip coupling, when travelling at a speed of 46 miles per hour.

The pressure of the air in the brake-cylinder was less than in the preceding case, and it was gradually diminished during the experiment; consequently the force with which the blocks pressed on the wheels diminished to the same slight extent, as shown by P P.

At first the friction between the brake-blocks and wheels also diminished very slightly; but when the velocity of the van had greatly

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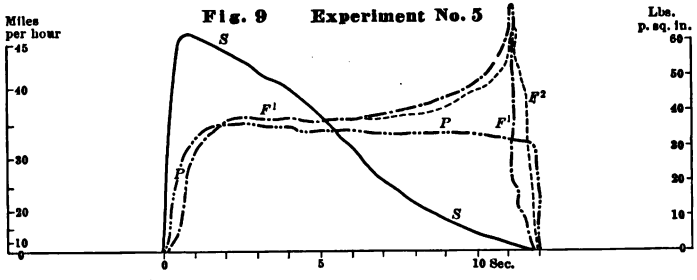
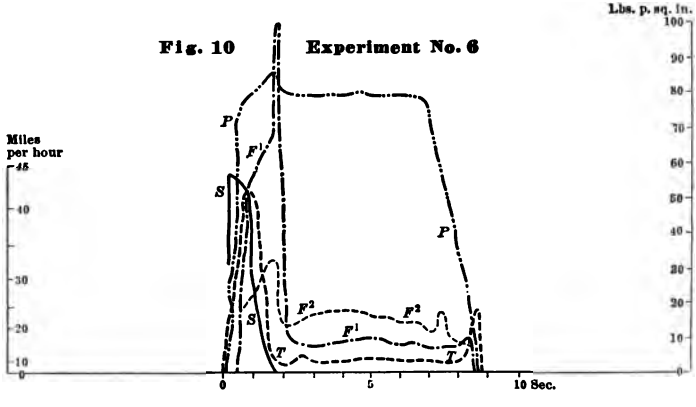
decreased, as shown by S S, the friction, as shown by F F, increased rapidly. The van came to rest in 12 seconds, without any jerk, before this friction had risen to a point sufficiently high to produce skidding.

These two diagrams, Figs. 8 and 9, afford a comparison of a stop



with skidding and one without skidding. The latter stop was effected, with a uniform motion without jerks, from a speed of 46 miles an hour, in 12 seconds; while the former required 12½ seconds to stop from a speed of 40 miles an hour, with a series of unpleasant jerks.



No. 6.

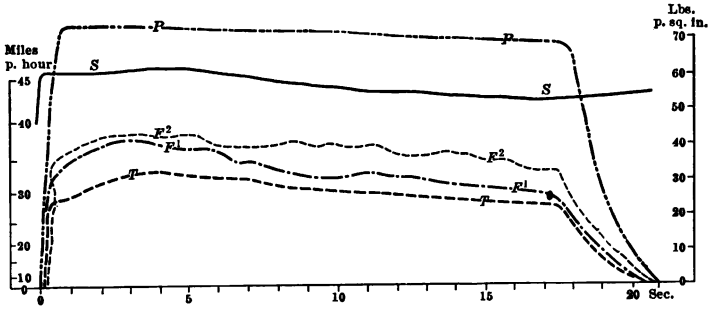
Fig. 10. (Exp. 3. 28th May.)—In this experiment the train's velocity was uniform throughout at 44½ miles an hour. The pressure

applied to the brake-blocks sufficed to skid the wheels at once, as shown by S S.

The line F F shows that the coefficient of friction between the brake-blocks and the wheels decreased immediately after the skidding, and only rose at the end of the experiment.

Line T T shows that the tractive force on the draw-bar increased with the act of skidding, but largely decreased as soon as the skidding was effected.

Fig. 11 Experiment No. 7



No. 7.

Fig. 11. (Ex. 21. 28th May.)—In this experiment the speed was 45 miles an hour at the beginning, and decreased to 42½ miles at the end.

The pressure was slightly decreased during the experiment; it did not suffice to skid the wheels; and the wheels with brakes and those without brakes revolved at the same rate, as shown by the Stroudley indicators.

The tractive force on the draw-bar, shown by T T, follows a nearly uniform line.

A comparison between this diagram, Fig. 11, and the preceding one, Fig. 10, shows that, although the pressure on the brake-blocks in the former case, in which the wheels were skidded, was greater than in this case, where the wheels were not skidded, yet the practical effect of the brakes, as shown by the tractive force on the draw-bar, was much greater with the wheels braked but not skidded (Fig. 11), than with the skidded wheels (Fig. 10).

Air Brake Tests

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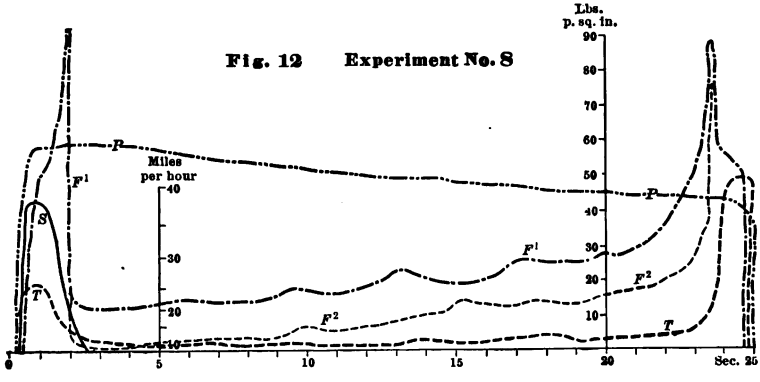
No. 8.

Fig. 12. (Exp. 9. 29th May.)—In this experiment the van and the engine were brought to rest by means of the brake from a speed of 40 miles per hour.

The wheels skidded very quickly after the brake was applied, as shown by the line S; the retarding force, shown by F F, rose



greatly at the moment of skidding, and then fell considerably below the original amount. The wheels remained skidded to the end of the experiment.

The diagram shows an increase in the coefficient of friction, measured by the rise in the friction line F F, and fall in the pressure line P P, as the train's velocity diminished; this increase was slight at first, but more rapid as the velocity became reduced, and was very great at the moment of stopping.

No. 9.

Fig. 13. (Exp. 3. 29th May.)—In this experiment the van and the engine were brought to rest from 39 miles an hour by means of the brakes upon both.

The compressed air in the brake-cylinder was allowed to escape through a small aperture after the brake was applied; and thus its

pressure, and consequently the force with which the blocks pressed against the wheels, diminished during the experiment, as shown by P P.

The line F F shows that the retarding force due to the pressure of the brake-blocks on the wheels at first diminished, until the reduction of velocity, shown by S, reached the point where the increase in the coefficient of friction was sufficient to overcome the effect of the diminished pressure applied to the brake-blocks. From this point the retarding effect of the brakes increased rapidly, and before long the wheels were skidded. Up to this point the two pairs of wheels of

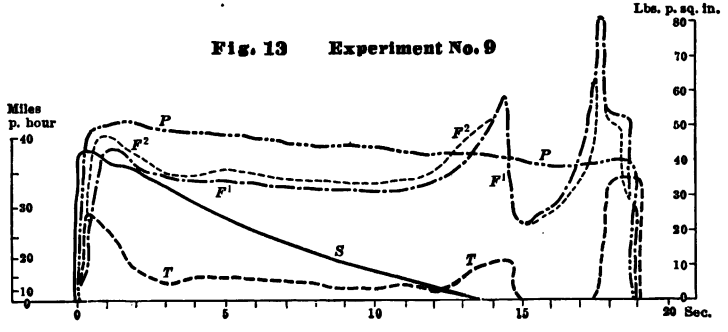


Fig. 13 Experiment No. 9

the van, to one of which brakes were applied whilst the other was running freely, had revolved approximately at the same rate, as shown by Mr. Stroudley's speed indicators. At the moment of skidding the friction curve F F rose in a nearly vertical line, thus showing that the coefficient of friction became very great as the wheels came to rest; and the time during which the wheels were partly rotating and partly slipping was almost inappreciable. Immediately after this rise the curve F F fell to a point far below its former level, thus showing a great diminution in the retarding effect of the brakes as soon as the wheels were skidded. After this point the curve rose again while the velocity continued to decrease; and thus showed that the coefficient of friction between the rails and the skidded wheels increased as the velocity of the train diminished. At the moment when the van came

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to rest the coefficient of friction became very great, as shown by the final rise in F F. The traction line T T varies greatly, according to the working of the brakes upon the engine and van respectively.

It is unnecessary in this preliminary paper to give the particulars of the reduction of the diagrams; but the principal results shown by them may be summed up as follows:—

1. The application of brakes to the wheels, when skidding is not produced, does not appear to retard the rapidity of rotation of the wheels.

2. When the rotation of the wheels falls below that due to the speed at which the train is moving, skidding appears to follow immediately.

3. The resistance which results from the application of brakes without skidding is greater than that caused by skidded wheels.

4. Just at the moment of skidding, the retarding force increases to an amount much beyond that which prevailed before the skidding took place; but immediately after the complete skidding has taken place, the retarding force fall down again to much below what it was before the skidding.

5. The pressure required to skid the wheel is much higher than that required to hold them skidded; and appears to bear a relation to the weight on the wheels themselves, as well as to their adhesion and velocity.

It would seem that the great increase in the frictional resistance of the blocks on the wheels just before and at the moment of skidding, due to the increase in the coefficient of friction when the relative motion of the blocks and the wheels becomes small, is what destroys the rotating momentum of the wheels so quickly.

With constant pressures, the friction between the blocks and the wheels, and consequently the retarding force, increases as the velocity decreases.

In order to obtain the maximum retarding power on a train, the wheels ought never to skid; but the pressure of the brake-blocks on the

wheels ought just to stop short of the skidding point. In order that this may be the case, the pressure between the blocks and the wheels ought to be very great when the brakes are first applied, and ought gradually to diminish until the train comes to rest.

There are other points of interest indicated by the diagrams which require further elucidation; among which may be mentioned the question whether the coefficient of friction diminishes when the pressure increases and the velocity remains constant. Another question is as to the practical effect on the wheels themselves resulting from the greater amount of work done by retarding the wheels without skidding, as compared with the effect of skidding.

The general conclusion which would appear to follow from the results of these preliminary experiments is that none of the hand brakes, and only some of the continuous brakes now in use, have been designed with a clear knowledge of the most essential conditions required in a perfect brake.

Experiments connected with the action of brakes on railway trains require very delicate apparatus; and the author in conclusion wishes to explain that the credit of the design of the apparatus used in these experiments, and of the successful manner in which the apparatus was applied, belongs entirely to Mr. Westinghouse. The efficiency of the arrangements for making the experiments which contributed to the successful results obtained is due to the London, Brighton & South Coast Railway Company, as represented by their locomotive engineer, Mr. Stroudley, who gave much personal attention to the work, and by Mr. Knight, the general manager, who afforded every facility for the use of the line.

ON THE EFFECT OF BRAKES UPON RAILWAY TRAINS.

(Second Paper.)

By Captain DOUGLAS GALTON, C. B., Hon. D.C.L., F.R.S., of London.

The experiments which the author brought to the notice of the Institution at the Paris meeting have since been continued, and the results then obtained have been more completely investigated.

The apparatus used was substantially the same as was described in the first paper. But for the new experiments, it has been somewhat altered by a rearrangement of the levers. The altered arrangement is shown in Figs. 14 and 15. In the first experiments the friction of each pair of brake-blocks upon the wheel was recorded on a separate diagram. By the rearrangement the levers from all the brake-blocks act on one dynamometer, and the friction of all the four brake-blocks applied to the pair of braked wheels is recorded on one diagram. The description of the manner in which these levers act, given in the first paper, applies generally to the altered arrangement. An addition was also made to the apparatus, for the purpose of obtaining the proportion of the weight of the van which rested on the braked wheels. To effect this, a dynamometer (No. 2), of similar construction to the others already described, was fixed to levers L L, as shown in Figs. 14 and 15, these levers being connected with the ends of the springs which support the body of the van above the unbraked wheels. From the diagrams furnished by the indicator for this dynamometer, the proportion of the weight of the body of the van resting on this pair of wheels was obtained.

The weight of the body of the van with the apparatus, etc., when stationary, was found to be as follows:—

On wheels not braked	8,764 lbs.
On braked wheels	9,436 lbs.
Total	18,200 lbs.

To this had to be added the weight of the persons in the van, and that of the wheels, axles, axle-boxes, and springs. The former was

assumed at 160 lbs. per person; an experiment made by weighing thirteen persons, who had traveled in the van on one of the days of the experiments, having given an average weight of 159 lbs. per person. The latter was obtained as nearly as possible from the records of the locomotive department of the Brighton Railway, and formed a constant quantity, one-half of which, with the allowance for the number of persons in the van, was added to the difference between the weight shown by the diagrams and the total weight of the body of the van, to obtain the weight on the braked wheels. This weight varied at almost every moment during the experiments, and the actual weight at the moment has in all cases been taken for calculating the adhesion.*

Preliminary Observations on the Experiments.—The author would in the first place observe that most of the conclusions given in the first paper will be found to be generally borne out by a further study of the diagrams; but some modification is required in the opinion expressed that, when the friction of the brake-blocks is sufficient to check the

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* The mode of action of the dynamometers used for measuring the various forces was described in the first paper; but as many questions have been asked of the author about the action of the supply valve E (Fig. 4), the following remarks are here added as a note.

In order to make the action of the valve more clear, let it be supposed that there is a constant force, such as a weight, acting on the piston B B, and that the whole apparatus is full of water. As the water slowly leaks past the piston of the indicator, the piston B B will slowly descend until the brass collar touches the top of the valve spindle. It will take some force to open the valve, on account of the excess pressure of water on its other side, and also on account of the spring which forces it on its seat; and this will introduce a small error in the reading of the indicator, as the whole weight will not be supported by the pressure of the water, and consequently the pressure will fall and the indicator pencil will stand too low.

As the leakage continues, the brass collar will force open the valve, and it will open it just so much as to allow the same quantity of water to enter as leaks past the indicator piston; for if more comes in than leaks out, the piston B B will be raised, and the valve will close slightly and thus diminish the quantity of water which enters; and if less comes in, the opposite takes place. In passing through the small opening of the valve the water is wire-drawn, and its excess pressure destroyed.

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rotation of the wheel, the rotation is immediately stopped altogether. On the contrary, a closer examination of the diagrams shows that in every case where the wheels become locked and slide on the rails, there occurs, just before this takes place, an appreciable interval of time during which the speed of rotation is gradually, though rapidly, diminished.

General Description of the Experiments.—The brake-blocks were applied to both sides of the wheels; that is to say, there were four brake-blocks to each pair of wheels. This arrangement prevents a strain being brought upon the axle. The blocks were made of cast-iron—wooden blocks being too soft, and wrought-iron blocks proving irregular in their action, apparently from a change in condition, owing to the high temperature evolved by friction. It would indeed seem probable that wrought-iron as well as steel blocks would prove injurious to the tires.

The experiments on the Brighton Railway, which were made with the experimental van and an engine, have been supplemented by some further experiments made on the North Eastern Railway with a train of twelve vehicles fitted with the Westinghouse brake and a similar train fitted with the Smith-Hardy vacuum brake.

The experiments on the Brighton Railway may be divided into two classes: (1) those made whilst the speed of the engine was kept up at an ascertained rate; (2) those made by slipping the van when the required speed had been obtained, and allowing the van to come to rest by the application of the brakes. In the first class of experiments the recording apparatus was set in motion by hand at a convenient time before the brake was applied; in the second class the recording apparatus was set in motion by the automatic application of the brake at the moment of separation from the engine.

The general action of railway brakes may be thus described: When a train is moving at a given velocity, the adhesion of the wheels on the rails causes them to revolve; every point on the surface of the tire moves round at the same rate as that at which the train itself is moving forward; but every such point, in relation to the forward movement of

the train, comes successively to rest at the moment when it comes in contact with the rail. Now, when the brake is applied with a slight pressure only, the wheel continues to move round at the same rate as the train is moving, but it moves with more difficulty, and this increased difficulty in moving is shown either by an increase in the tractive force required to keep up the forward motion, or, in cases where the accelerating force is not kept up, by the tendency of the moving mass to come to rest in a shorter time than would otherwise be the case. But if the pressure with which the brake is applied be increased, a point is reached when the friction between the brake-block and the wheel first approaches, then equals and finally exceeds the adhesion of the wheel on the rail, which adhesion corresponds with the static friction between the surfaces, because the part of the tire in momentary contact with the rail during its rotation, is for that moment at rest in relation to the forward movement of the train. When this happens, the wheel first begins to revolve more slowly, and then ceases to revolve and slides along the rail, or, as it is usually termed, is skidded. In this case the retardation is no longer due to the pressure upon the brake-block and consequent friction between the brake-block and the tire of the wheel; but the vehicle is transformed for the time from a vehicle on wheels into a sledge, and the retardation due to the brakes is thus the excess of resistance which is produced by making the vehicle slide along the rails, over that produced by making the vehicle move forward on wheels revolving freely.

It is therefore necessary to consider the experiments under these two different conditions of retardation, and we arrive at the two following conclusions :—

(A) So long as the wheels continue to revolve, the measure of retardation is the friction between the brake-blocks and the wheels, and this is represented by :—

The coefficient of friction between the brake-blocks and the wheels × the pressure applied to force the blocks against the wheels.

(B) As soon as the wheel begins to slide on the rail, the measure of

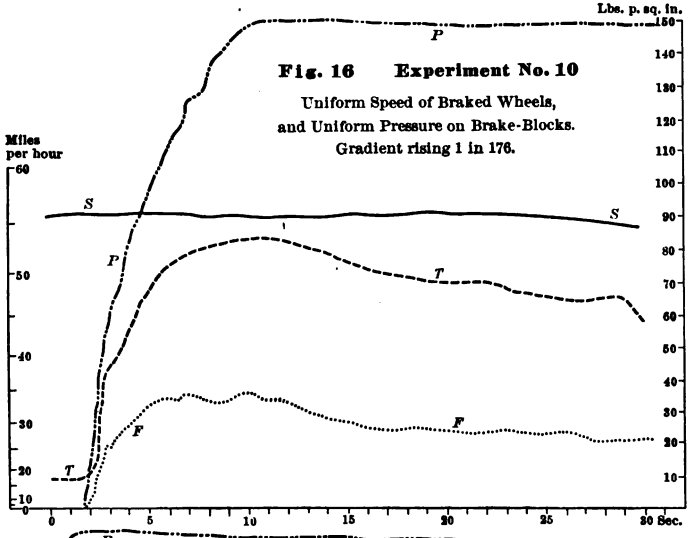

Fig. 16 Experiment No. 10

Uniform Speed of Braked Wheels,
and Uniform Pressure on Brake-Blocks.
Gradient rising 1 in 176.

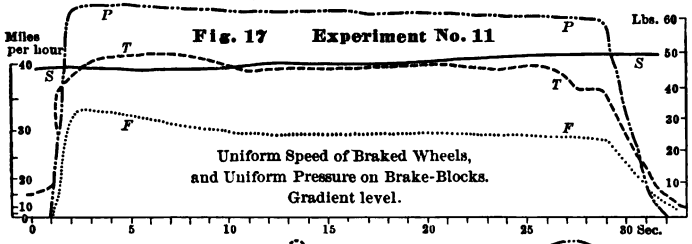

Fig. 17 Experiment No. 11

Uniform Speed of Braked Wheels,
and Uniform Pressure on Brake-Blocks.
Gradient level.

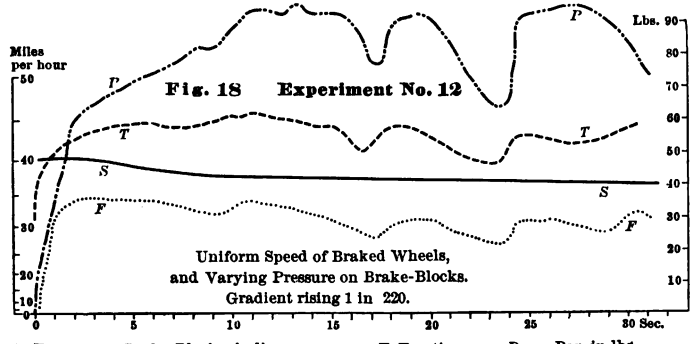

Fig. 18 Experiment No. 12

Uniform Speed of Braked Wheels,
and Varying Pressure on Brake-Blocks.
Gradient rising 1 in 220.

P Pressure on Brake-Blocks, in lbs. *T* Traction upon Draw-Bar, in lbs.
F Friction between Brake-Blocks and Wheels. *S* Speed of Braked Wheels, miles p. hour.

retardation is the friction between the wheel and the rail (which is equal to the strain exerted by the brake-blocks to hold the wheels in their fixed position), and this is represented by :—

The coefficient of friction between the rails and the wheels × the weight upon the wheels.

In considering these experiments, it will therefore be convenient to class the results obtained under the following heads :—

1. *The coefficient of friction between the brake-blocks and the wheels.*
2. *The coefficient of friction between the wheels and the rails.*
3. *The general effect of the application of the brakes in retarding the train, as shown by the strain on the draw-bar.*
4. *The proportion which the pressure applied to the brake-blocks should bear to the weight on the wheels at different velocities.*
5. *The effect of the time expended in bringing the pressure to bear on the wheels.*

1. *Coefficient of friction between the brake-blocks and the wheels.*

The diagrams* shown in Figs. 16 to 18 will conveniently illustrate this question. During each of these experiments the velocity of the braked wheels was uniform, as shown by the line S S. In Fig. 16 the pressure on the brake-blocks was also uniform, as shown by the line P P. In Fig. 18 the pressure P was made to vary.

It appears from Fig. 16, where the pressure and velocity were practically uniform, that the friction diminishes as the time of application of the brakes continues. This is shown by the fall in the friction line F F.

* The multipliers required in the present series of diagrams for reducing the ordinates to actual lbs. of force are somewhat different from those in the former series (see p. 31). They are here as follows :—

Line F F, No. 1.	Dynamometer	(total friction on blocks)	60 before skidding. 67.5 during do.
Line P P, No. 3.	do.	(total pressure on blocks)	240.
Line T T, No. 4.	do.	(total traction on draw-bar)	30.
Line S S, No. 5.	do.	(speed of braked wheels)—to scale.	

Air Brake Tests

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It appears from Fig. 18, that the friction varies with the pressure, the friction line F F following the rise and fall of the pressure line P P; and it appears by comparing Fig. 16, where the velocity was 55 miles an hour, and Fig. 17, where the velocity was 40 miles an hour, with Fig. 20, where the velocity was only 15 miles an hour, that the proportion of friction to pressure was greater at the lower than at the higher velocity. This latter fact is further shown in Fig. 19, where the experiment commenced at a speed of 52 miles an hour, and ended with the train coming to rest. In this case the effect of time on the application of the brakes came into play at first, and the friction became somewhat reduced; but when the velocity had seriously diminished, the friction rapidly increased until it nearly approached the value of static friction. The proportion which exists between friction and pressure is the coefficient of friction, and it thus appears that *the coefficient of friction increases as the velocity diminishes; and diminishes, at any rate when the surfaces are steel and cast-iron, as the time increases during which the pressure has been applied.*

Some special experiments were made with blocks of small area. The brake-blocks generally used in these experiments were 12 inches long by 3 inches wide, giving a surface of 36 square inches; the small brake-blocks were made so as to afford a surface of pressure against the wheel of only one-third of this amount, or 12 square inches, thus making the pressure per square inch three times as great as before. The diminution of surface was obtained by casting projections upon the face of the block. The author is not prepared to say that any greater coefficient of friction was obtained by the extra pressure per square inch, although in one of the experiments, Fig. 21, at a velocity of 60 miles an hour, the rotation of the wheels was arrested by these blocks, whilst this effect had not been produced at that speed in other experiments. The experiments on this form of block were stopped because the blocks were entirely worn down in the course of about twelve experiments.

Mr. Rennie showed* that high pressure per square inch produced a

* Phil. Trans. for 1829, p. 159.

greater coefficient of friction between surfaces either moving very slowly or nearly at rest; but it must be borne in mind that the author's experiments were made with high velocities, whereby a serious element of disturbance is introduced, viz., the grinding away of the surface; and it is therefore probable that the increase in the coefficient of friction due to increased pressure may have been neutralised by the lubricating effect of the fine particles ground off the surfaces.

While the author refrains from expressing any certain opinion as to the relation which the coefficient of friction bears to pressure, so far as these experiments are concerned it is quite clear that in proportion as the pressure is increased or diminished so will the actual friction obtained be increased or diminished. When the friction which exists between the brake-blocks and the wheel thus reaches a certain point, the wheel ceases to rotate and becomes fixed. This point is reached when the frictional resistance of the blocks exceeds the adhesion between the wheel and the rail if the speed is kept up; or, if the speed is slackening, when it exceeds the adhesion between the wheel and the rail, plus the effort required to retard the rotation of the wheel equally with the retardation of the train; and the excess of resistance then acts as an unbalanced force, tending to destroy the momentum of the wheel. As far as can be judged from the experiments, it would seem that, whether the speed be high or low, nearly the same absolute amount of frictional resistance is required to skid the wheel, other things being equal; but that the time during which the rotation of the wheel is slackening, before it is completely stopped, varies with the speed. Thus it would appear from a comparison of Fig. 20 with Fig. 21, that whilst at 15 miles an hour the wheel skidded in about ¾ second, at 60 miles an hour it required about 3 seconds to skid the wheel.

The amount of frictional resistance which determines the point at which the rotation of the wheels is checked varies, it is true, in the different experiments. The ratio which it bears to the weight upon the braked wheels is in some cases as low as .19; and in some cases

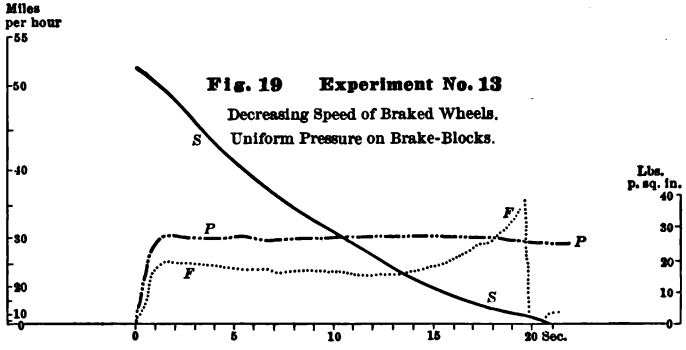

Fig. 19 Experiment No. 13

Decreasing Speed of Braked Wheels.
Uniform Pressure on Brake-Blocks.

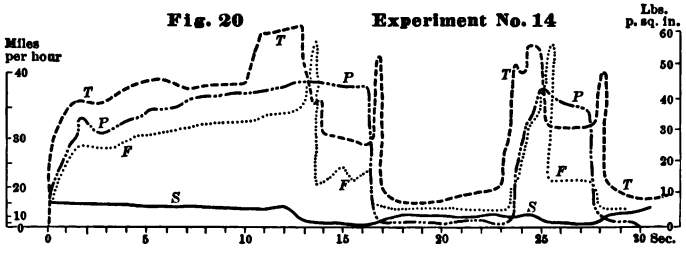

Fig. 20 Experiment No. 14

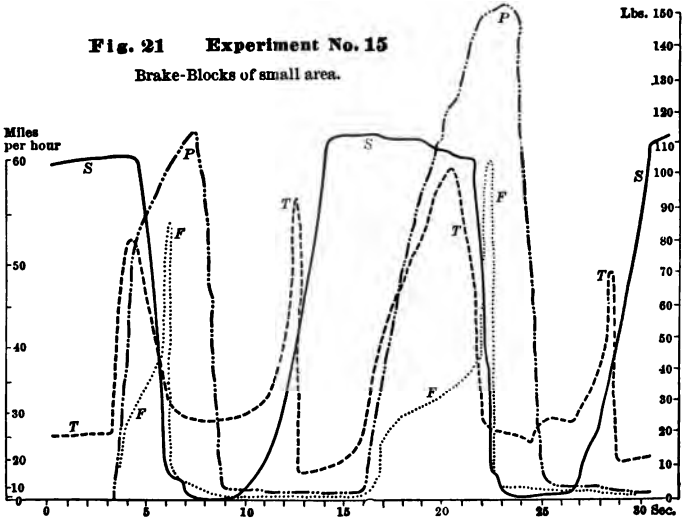

Fig. 21 Experiment No. 15

Brake-Blocks of small area.

as high as .35 or even somewhat more, the average being about .25 of the weight on the wheels. But it clearly represents simply the adhesion between the wheel and the rail, and varies only with this, and not with the speed. Thus in Fig. 21, where the velocity was 60 miles an hour, the amount of actual frictional resistance which checked the rotation of the wheels was about 2,000 lbs., exhibiting an adhesion of about 19.1 per cent. Again, in Fig. 20, where the velocity was 15 miles an hour, the actual amount of friction appears to have been about 2,160 lbs., exhibiting an adhesion of about 19.6 per cent.* As these two values are so nearly equivalent, it would thus appear that the effort retarding rotation is much the same at all speeds; and therefore that the point at which the retardation of the rotation of the wheels commences does not vary with the momentum of the wheels, but depends entirely upon the adhesion between the wheel and the rail.

It will be observed in Figs. 20 and 21, where the wheel was skidded, while the train went on, as well as in Fig. 19, in which the experiment commenced at a high velocity and ended with the stopping of the train, that just before rest, at the moment when the rotation of the wheel was stopped, a considerable increase in the amount of friction took place. At this point the coefficient of friction will be found to correspond with the coefficient which has been noted by former observers as that of static friction, or of friction between surfaces moving at very slow velocities. The sudden jump in the diagrams shows the sudden change from the one coefficient of friction to the other, at the moment of the wheels ceasing to rotate. In some instances the friction thus developed amounted to .30 and even .325 of the pressure, which is about equivalent to the coefficient of static friction between steel and cast-iron, as given in Rennie's experiments.

It has been shown above that, whether the velocity be high or low, the period at which the rotation of the wheel is stopped, so that it slides on the rail, depends upon the amount of friction between the

* In this and other cases the diagrams exhibited are merely specimens of a very large number in the author's possession, all leading to the same conclusion.

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brake-block and the wheel, the weight upon the wheel, and the condition of the rails, which governs the adhesion between the wheel and the rail. Therefore, with the same weight on the wheels, and the rails in a similar condition, the same amount of brake friction will stop the rotation of the wheels whatever be the speed. The manner in which speed affects this question is due to the fact that in order to obtain the same absolute amount of frictional resistance at a high speed as at a low speed a greater pressure is required.

For instance, selecting at random two experiments (No. 16 and 13, of the 22d July), in the first, with a speed of about 16 miles an hour, a pressure of 8,169 lbs. applied to the brake-blocks produced a friction of 1,560 lbs; whilst in the second, with a speed of about 50 miles per hour, a pressure of 13,900 lbs. applied to the brake-blocks produced a friction of only 1,400 lbs.

There is much difficulty, however, in satisfactorily establishing the coefficient of friction which obtains at different velocities, owing to the fact that the time during which the pressure is continued to be applied enters so largely into the amount of friction produced by a given pressure. Thus in Fig. 16, with a speed of from 55 miles falling to about 53 miles per hour, a pressure of 35,000 lbs. at the commencement of the experiment produced a frictional resistance of about 2,000 lbs., whilst after 10 seconds the amount of frictional resistance had diminished to 1,400 lbs., although the pressure maintained was the same. Similarly, in experiment No. 31 of 23d August, at a speed of 30 miles an hour, a pressure of 12,000 lbs. produced at first a frictional resistance equivalent to 1,860 lbs.; but after 10 seconds this amount had fallen to 1,260 lbs., although the pressure had been raised to 13,440 lbs. It thus appears that the amount of friction is greatly diminished as the surfaces continue in contact. But the full pressure cannot be applied absolutely instantaneously; and however short the interval of time between the commencement of the experiment and the point at which the friction and pressure are measured, that interval is sufficient to affect the proportion which the friction bears to the pressure.

The experiments with which the author has had to deal are more-

over so numerous, and their reduction has been a work of so much labour, that he is not yet prepared to say that the coefficient of friction which he is about to give may not be liable to some modification when he has had time for further collation of the results. With this reservation he appends the following table, which gives, it is believed, a fair approximation to the coefficient of friction at different velocities between cast-iron brake-blocks and steel tires as used in these experiments.

TABLE I.— STATIC AND DYNAMIC FRICTION.

	VELOCITY.		COEFFICIENT OF FRICTION.					
				Obtained Approximately from Recent Experiments.				
	Feet per Second.	Miles per Hour.	Noted by Former Observers. See Fleeming Jenkin, Phil. Trans. for 1877.	At Commencement of Experiment.	After 5 Seconds.	After 10 Seconds.	After 15 Seconds.	After 20 Seconds.
Static Friction.								
MORIN.— Iron on Iron	Nil	Nil	.44					
RENNIE { Steel on Cast-Iron at pressure of 180 lbs. per square inch.	Nil	Nil	.300					
do. { at 336 lbs. per square inch.	Nil	Nil	.347					
FLEEMING JENKIN.— Steel on Steel	.0002 to .0086	Inappreciable	.351 mean, .365 max.					
Dynamic Friction. Cast-iron on Steel.								
Just before coming to rest	1 to 3	⅔ to 2	. .	.250				
When moving at . .	10	6.8	. .	.242				
do. . .	20	13.6	. .	.213	.193			
do. . .	25	17.0	. .	.205	.157	. .	.110	
do. . .	30	20.4	. .	.182	.152	.133	.116	.099
do. . .	40	27.3	. .	.171	.130	.119	.081	.072
do. . .	45	30.7	. .	.163	.107	.099		
do. . .	50	34.1	. .	.153				
do. . .	55	37.5	. .	.152	.096	.083	.069	
do. . .	60	40.9	. .	.144	.093			
do. . .	70	47.7	. .	.132	.080	.070		
do. . .	80	54.5	. .	.106	. .	. .	.045	
do. . .	88	60.0	. .	.072	.063	.058		

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This table indicates clearly the decrease in the coefficient of friction dependent upon increased velocity, and also the decrease due to the increased time during which the surfaces continue in contact. Further collation of the results of the experiments already obtained will however be necessary before an endeavor is made to deduce the actual laws of these decreases.

A certain number of experiments were made with wrought-iron blocks ; the results, so far as the coefficient of friction is concerned, are shown in the following table :—

TABLE II.—FRICTION OF WROUGHT-IRON BLOCKS ON STEEL TIRES.

VELOCITY.		COEFFICIENT OF FRICTION. Wrought-Iron Blocks and Steel Tires.		
Feet per Second.	Miles per Hour.	At Commencement of Experiment to 3 Seconds.	At from 5 to 7 Seconds.	At from 12 to 16 Seconds.
70	48	.110		
45	31	.129	.11	.099
26	18	.170		

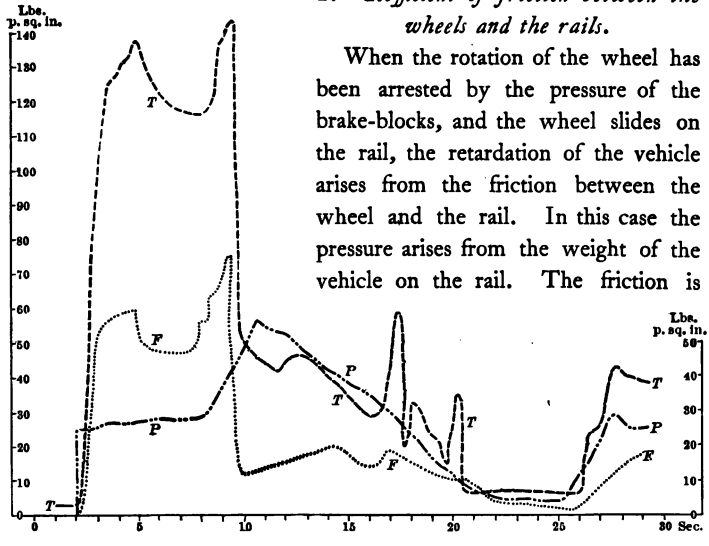
These blocks were not satisfactory in their operation. The surface seemed to be much affected by the increased temperature resulting from the friction, and jerks were produced which threatened to damage the apparatus.

The effect of sand on the rail, when fairly delivered under the wheel, is largely to increase the adhesion, both of the blocks and of the rails. Fig. 22, where the van was started from rest, exemplifies this. The average coefficient of friction whilst the wheels were revolving was .278, which is a much larger value than those given in Table 1. Just before the skidding took place the frictional resistance was equal to about 4,400 lbs., or nearly .46 of the pressure applied, and about .40 of the weight on the braked wheels ; which represents, therefore, the adhesion of the sanded rails. In the case of wet and greasy rails, sand appeared to make the adhesion about equal to that of a dry rail ; but on

a dry rail at high speeds sand did not appear to produce much effect, probably from being scattered by the wind caused by the motion of the van.

It must always be borne in mind, in discussing these experiments, that, when high speeds are used, the disturbing causes are so great that it is only from the average of a large number of experiments that useful results can be obtained.

Fig. 22
Experiment No. 16
Van starting from rest.
Sand on rails.



2. *Coefficient of friction between the wheels and the rails.*

When the rotation of the wheel has been arrested by the pressure of the brake-blocks, and the wheel slides on the rail, the retardation of the vehicle arises from the friction between the wheel and the rail. In this case the pressure arises from the weight of the vehicle on the rail. The friction is measured by the force which is exerted in holding the wheel in its fixed position, or by the force required to draw the skidded wheel along the rail, over and above that required when the wheel rotates freely. The experiments show that these forces are practically the same in amount.

The experiments on the Brighton Railway were made chiefly upon steel rails; but a certain number were made on a portion of the line where iron rails are in use. The following table gives approximately the coefficient of friction derived from these experiments :—

TABLE III.—DYNAMIC FRICTION BETWEEN WHEEL AND RAIL.

APPROXIMATE VELOCITY.		COEFFICIENT OF FRICTION.	
Feet per Second.	Miles per Hour.	Steel Tire on Steel Rail.	Steel Tire on Iron Rail.
Just coming to rest . .	. .	.242	.247
10	6.8	.088	.095
20	13.6	.072	.073
40	27 3	.070	
50	34.1	.065	.070
60	40.9	.057	
70	47.7	.040	.060
80	54.5	.038	
88	60.0	.027*	

* This is from a mean of three experiments only.

It will be observed that there is some difference between the friction as noted with steel tires on iron rails, and with steel tires on steel rails; the proportion which the friction bears to the pressure, or the coefficient of friction, is greater in the case of iron rails than in the case of steel rails.

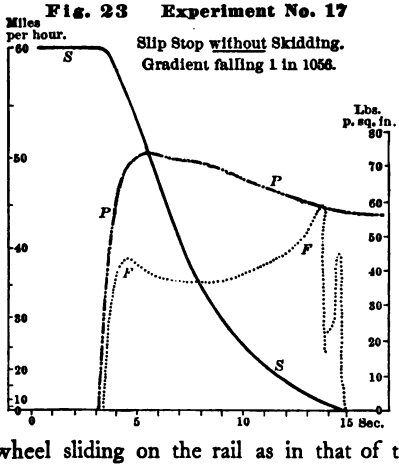


Fig. 23 Experiment No. 17
Slip Stop without Skidding.
Gradient falling 1 in 1056.

The diminution in the coefficient of friction arising from the increasing time during which the surfaces are in contact is not so marked in the case of the wheel sliding on the rail as in that of the wheel revolving against the brake-blocks.

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The practical inference to be drawn from the results which have been obtained, as to the low coefficient of friction when the wheels slides on the rail, is exemplified in the experiments made on the Brighton Railway, where the van was detached from the engine when traveling at an ascertained speed, and allowed to come to rest. The diagrams shown in Figs. 23 and 24, afford a fair example of the disadvantage of applying such an amount of pressure as will cause sufficient friction to stop the rotation of the wheels, in cases where a rapid stop is required. In Fig. 24 the pressure applied amounted to 24,010 lbs.;

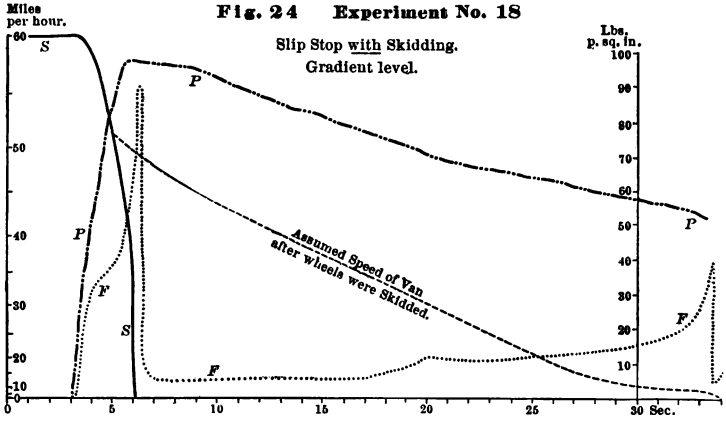

Fig. 24 Experiment No. 18

Slip Stop with Skidding.
Gradient level.

this was rather more than twice the weight on the wheels, and was sufficient after a diminution had taken place in the speed of the van from 60 miles to somewhere about 52 miles per hour, to arrest the rotation of the wheels. On the other hand, in Fig. 10, the maximum pressure applied was about 17,500 lbs., which did not produce sufficient friction to arrest the rotation of the wheels. In the experiment shown in Fig. 23 the van came to rest in 11½ seconds and in a distance of 189 yards, on a descending gradient of 1 in 1056; in the experiment shown in Fig. 24 the van was more than 30 seconds in coming to rest on a level, and ran a distance of above 400 yards.

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3. *General effect of the application of the brakes in retarding the train, as shown by the strain on the draw-bar.*

The application of pressure to the brake-blocks, and the friction thereby produced, causes an immediate strain on the draw-bar proportional to this friction. This is very clearly shown in Figs. 16, 17, 18, 25, 26, and 27, which are all selected from cases where the experiments took place on ascending gradients or on a level. It will be observed in these diagrams that the actual amount of friction increases with the pressure, up to a certain point; and then, if the friction is not sufficient to stop the rotation of the wheel, the decrease in the coefficient of friction, arising from the time during which the surfaces are in contact, causes the actual friction to decrease; and the strain on the draw-bar regularly follows the line of this decreasing friction. If, on the other hand, the pressure and consequent friction is sufficient to stop the rotation of the wheel, the strain on the draw-bar falls at once, on the rotation being checked, to a point corresponding with the diminished retardation resulting from the sliding of the wheel on the rail, as compared with the retardation caused by the friction of the brake-blocks on the wheel whilst the adhesion between wheel and rail acts freely to cause rotation. The draw-bar strain thus shown was in some cases not much more than twice as great as the ordinary tractive force previously shown to exist before the brake was applied.

Were there no disturbing causes when the brakes are applied to the wheels, and were a uniform speed maintained without skidding, the difference between the tractive force, or strain on the draw-bar, exerted after, and that exerted before, the application of the brakes would be equal to the friction between the brake-blocks and the wheels; and thus the friction between the brake-blocks and the wheels is the measure of the retardation caused by the action of the brakes on the train.

The next point to which attention may be directed in the diagrams is the following. When the rotation of the wheels has been arrested, the strain on the draw-bar, as already observed, becomes much less than that which prevailed whilst the wheels to which the brakes are applied continue to rotate; but when the pressure applied to the brake-blocks

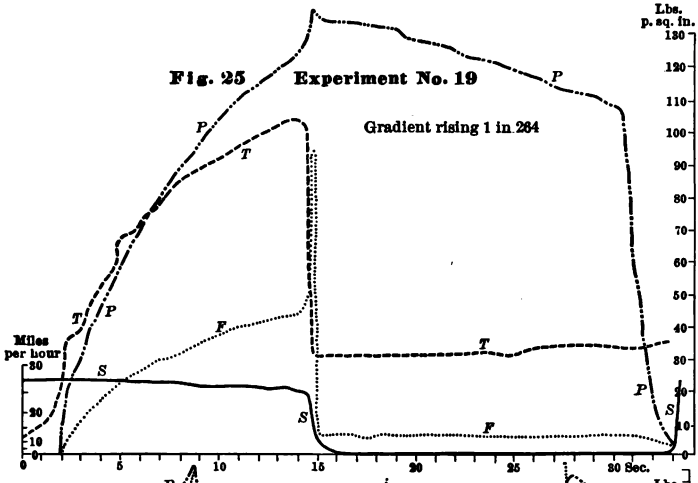
Fig. 25 Experiment No. 19
Gradient rising 1 in 264
Lbs. p. sq. in.
Miles per hour
P
T
F
S
0 5 10 15 20 25 30 Sec.

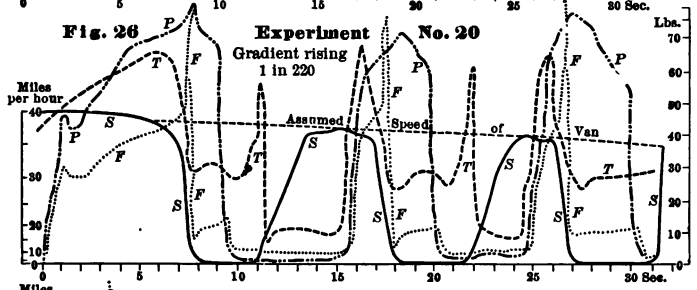
Fig. 26 Experiment No. 20
Gradient rising 1 in 220
Assumed Speed of Van
Lbs.
Miles per hour
P
T
F
S
0 5 10 15 20 25 30 Sec.

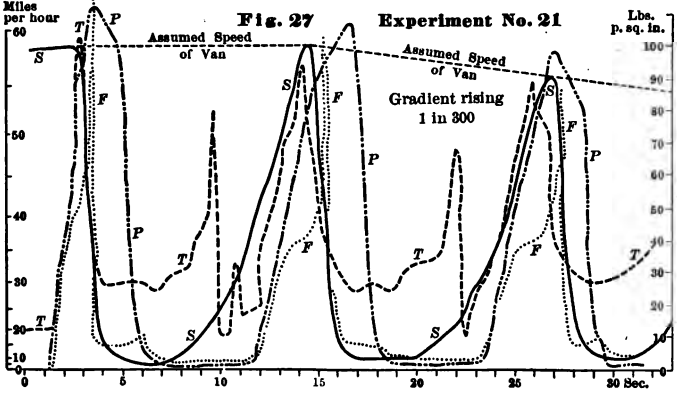
Fig. 27 Experiment No. 21
Assumed Speed of Van
Assumed Speed of Van
Gradient rising 1 in 300
Lbs. p. sq. in.
Miles per hour
P
T
F
S
0 5 10 15 20 25 30 Sec.

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is removed, so that the wheels whose rotation had been arrested begin to revolve again, this release of the wheels, at the moment when they take up their rotation, occasions a sudden strain on the draw-bar; because the adhesion between the wheels and the rails then comes into operation, and holds the wheels so as to compel them to rotate.

Thus in Fig. 21 the friction between the brake-blocks and the wheels, which determined the point of skidding, was about 1,980 lbs., equivalent to .19 of the weight on the wheels; this is the value of the adhesion between the wheels and the rails in the experiment in question. Now it will be seen that at the moment when the wheels were beginning to rotate, after the skidding, a strain was brought on the draw-bar of from 1,900 to 2,000 lbs. (or from .19 to .20 of the weight upon the wheels) in excess of the average strain which the draw-bar showed after the wheels had acquired the rotation due to the forward movement of the train. Thus the extra strain on the draw-bar due to the wheels again taking up their rotation was equal to the adhesion, in the experiment in question; and this appears to be the case generally.

4. *Proportion which the pressure applied to the brake-blocks should bear to the weight on the wheels at different velocities.*

The main practical advantage to be derived from the information given by these experiments, as to the coefficient of friction between brake-blocks and wheels, is the assistance which it affords towards determining the degree of pressure that should be applied to the brake-blocks in order to produce the required amount of retardation.

It is the adhesion between the wheel and the rail which governs this question, and if the adhesion were always uniform the rule would be very simple; but this is not the case.

In the experiments now under discussion, the adhesion appears to have been on an average about .24 to .25 of the weight, but it was sometimes below .19, and sometimes higher than .25. Now it is clear that (1) the pressure which, if applied, would stop the rotation of the wheels when the adhesion is low is much less than that which

would stop the rotation when the adhesion is high; and (2) the higher the pressure which is applied, short of that which stops the rotation of the wheels, the greater is the friction and the consequent retardation of the train.

The following table gives approximately the proportion which the pressure to be applied to the brake-blocks should bear to the weight upon the braked wheels, with coefficients of adhesion between wheel and rail varying from .30 to .15 of the weight on the wheels :—

TABLE IV. — RATIO OF BRAKE-BLOCK PRESSURE TO WEIGHT ON WHEELS.

SPEED.		APPROXIMATE RATIO of Total Pressure on Brake-blocks to Total Weight on Braked Wheels.			
Feet per Second.	Miles per Hour.	Coefficient of Adhesion, 0.30.	Coefficient of Adhesion, 0.25.	Coefficient of Adhesion, 0.20.	Coefficient of Adhesion, 0.15.
11	7½	1.20	1.04	0.83	0.60
22	15	1.41	1.18	0.94	0.70
29	20	1.64	1.37	1.09	0.82
44	30	1.83	1.53	1.22	0.92
59	40	2.07	1.73	1.38	1.04
73	50	2.48	2.07	1.65	1.24
88	60	4.14	3.47	2.77	2.08

It will be seen that, when the adhesion equals .30 of the weight, a pressure equal to 1.2 of the weight would skid the wheel at 7½ miles per hour, whilst a pressure equal to 4.14 times the weight would be required to do so at 60 miles per hour. On the other hand, if the adhesion is only .15, the pressure requisite to skid the wheel would be only .60 of the weight at 7½ miles per hour, and 2.08 of the weight at 60 miles per hour.

Thus the efficiency of a brake depends upon the pressure being proportioned to the speed and to the adhesion. Therefore every engine should be provided with a speed-indicator, in order that the driver may know with certainty the speed at which he is travelling.

At present no means are in use by which the pressure can be regulated with a due regard to the adhesion, beyond those dependent upon

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the judgment of the engine driver. There is, however, no reason why, in the progress of mechanical science, both the above conditions should not be regulated by a self-acting arrangement. It may be added that the adhesion, and consequently the retarding effect of the brakes, would be greatly increased were means devised for placing sand under every wheel to which a brake is applied during the progress of a stop.

5. *Effect of the time expended in bringing the pressure to bear on the wheels.*

The experiments made with the experimental van on the Brighton Railway showed the following results as to the times of stopping of the van, when released from the engine by a slip-coupling, at various speeds, and with both pairs of wheels braked :—

TABLE V.—STOPS OF VAN WITH BOTH PAIRS OF WHEELS BRAKED.

Date and No. of Experiment.	Speed. Miles per Hour.	Gradients.	Distance of Stop. Yards.	Time of Stop. Seconds.	Average Retardation in Miles per Hour per Second.	Ratio of Retarding Force to Weight on Wheels.*
24 July, No. 25	30	Level	63	8¾	6.8	.16
24 July, No. 28	32	do.	75	7½	4.2	.15
25 July, No. 25	40	do.	84	9	4.5	.20
25 July, No. 26	40	do.	85	9	4.5	.20
22 Aug., No. 21	53	do.	145	12	4.6	.21
23 Aug., No. 10	52	Fall 1 in 176	151	11½	4.5	.19
24 July, No. 21	60	Level	187	11¾	4.7	.21
22 Aug., No. 7	60	do.	189	12	5.2	.21
23 Aug., No. 18	52	do.	215	15	3.5	.14

The rapidity of the stop depends much upon the rapidity with which the brakes are brought to bear on the wheels. This is illustrated by Figs. 28 and 29. In Fig. 28, the speed was 52 miles an hour ;

* This ratio is deduced from the formula $f = \frac{V^2}{2gl}$, where f = ratio of retarding force to weight on wheel, V = initial velocity of train in feet per second, l = feet run in coming to rest. The effect of gradients is neglected.

the full pressure was brought on immediately, and the van was brought to rest in 11½ seconds and in 151 yards, on a descending gradient of 1 in 176. In Fig. 29 the speed was about 52 miles an hour; the pressure was applied gradually, beginning to be brought on after 1 second, and the stop took place in 15 seconds and in 215 yards on a level. It is thus abundantly clear that the rapidity with which the pressure can be applied to the wheels through the medium of the brake-blocks materially influences the rapidity of the stop.

This points to the advantage of being able to move the brake-blocks with great rapidity from their position of inaction to that of contact with

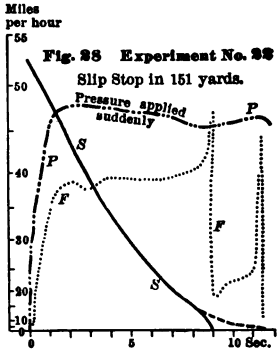

Fig. 28 Experiment No. 28
Slip Stop in 151 yards.

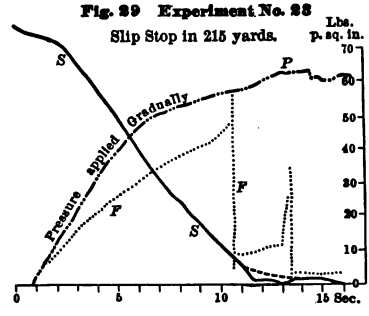

Fig. 29 Experiment No. 28
Slip Stop in 215 yards.

the wheels; because it is essential to provide that the brake-blocks, when out of use, shall be removed to a distance from the wheels sufficient to prevent the possibility of their dragging against the wheels, and thus causing retardation to the progress of the train. The question of the rapidity with which brakes can be applied in practice is thus one of much importance. Through the courtesy of the Directors of the North Eastern Railway, and their General Manager, Mr. Tennant, the author was enabled to make some experiments upon two trains, one fitted with the Westinghouse brake, the other with the Smith-Hardy Vacuum brake; the object being to ascertain the rate at which the pressure upon the brake-blocks is applied in practice to the wheels of a train, in four different parts of the train, viz.:—

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1st, Next to the engine;
2nd, At a distance of six carriages from the engine;
3rd, At a distance of twelve carriages from the engine;
4th, At a distance of twenty carriages from the engine.

The trains upon which these experiments were made were as follows:—

TABLE VI.—WEIGHTS OF TRAINS.

	Total Weight.			Weight on Braked Wheels.		
	Tons.	Cwt.	Qrs.	Tons.	Cwt.	Qrs.
Westinghouse Train.—						
Engine { Leading Wheels	10	18	0			
Engine { Driving do.	14	9	0	14	9	0
Engine { Trailing do.	9	10	0	9	10	0
Tender	22	13	0	22	13	0
2 Vans	15	16	2	15	16	2
Carriages—6 Composite	56	11	3	56	11	2
7 Third-Class	34	12	3	34	12	2
Experimental Van	9	12	0	9	12	0
Total Westinghouse Train	174	3	0	163	4	2
Vacuum Train.—						
Engine { Leading	12	10	0			
Engine { Driving	14	0	0	14	0	0
Engine { Trailing	12	15	0	12	15	0
Tender	26	4	0	26	4	0
2 Vans	15	16	2	15	16	2
Carriages—3 Composite	28	2	1	28	2	1
7 Third-Class	60	12	0	60	12	0
Experimental Van	9	12	0	9	12	0
Total Vacuum Train	179	11	3	167	1	3

Therefore, in the case of the Westinghouse train, 93.7 per cent. of the weight, and in the case of the Vacuum, 94.4 per cent. of the weight, was on the braked wheels. The weight of the engine and tender resting on braked wheels was, in the case of the Westinghouse, 26.7 per cent., and in the case of the Vacuum, 29.4 per cent., of the whole weight of the train.

The recording apparatus in the van was set in motion by means of an electric connection with the brake lever attached to the engine.

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The author had intended this to come into operation at the first movement of the brake lever; but by the arrangement made the lever could move through two-thirds of its stroke before setting the apparatus in motion; so that, when the handle of the lever was moved slowly, any action on the brakes which might take place before this point had been reached would not be recorded.

The Westinghouse train was a train which had been working in regular traffic, and was run in practically the same condition as when running on the line, except that it was put in good order. The Vacuum carriages and engine were altered from what had been their condition on the North Eastern Railway, by the substitution of the Hardy cylinders for the Smith Vacuum sack, and by alterations in the ejector on the engine. On the ordinary passenger engines of the North Eastern Railway the bottom nozzles of the ejector are 2 in. diameter, and the top nozzles 2 3/8 in., and the steam pipe 1 3/4 in. In the experimental engine one of the bottom nozzles was 2 3/8 in. diameter, and the other 2 in. diameter: the top nozzles 2 7/8 in. diameter and 2 3/8 in. respectively, and the steam pipe 2 in. inside diameter. The leverage was also much more powerful than that in use on the other passenger engines of the North Eastern Railway, so that a very high pressure could be applied to the engine wheels. These alterations, it was stated, were made in order to place the train in the same condition as trains recently fitted up on other lines.

It was intended that the brakes should be so arranged that each brake-block, when in a state of inaction, should be removed a full quarter of an inch from the surface of the wheel, so as to ensure that there should be no dragging. This condition was fulfilled in the Westinghouse train; but in the Vacuum train the blocks, except in two or three instances, were much closer, indeed often less than 1/8 inch, and in some cases less than 1/16 inch from the tire of the wheel. The Westinghouse train, as well as the experimental van, was fitted with continuous draw-bars. The Vacuum carriages had not continuous draw-bars.

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The experiments were commenced by putting the van next the engine, and so running from York to Knaresboro'; the van was then turned and placed at the tail of the train on the return journey.

After the Vacuum train had made six stops with the van next the engine, during the journey to Knaresboro', while making a stop on an ascending gradient of 1 in 120, a coupling-hook broke in the leading van, next behind the experimental van. A fresh connection was made, but it was found, on returning to York, that the vacuum cylinder on the tender, for working the engine brakes, had become detached; this was apparently caused by a want of sufficient play in the lever connecting the Hardy cylinder with the engine brake. The experiments subsequent to the fracture rest under a doubt, therefore, as to representing truly the performance of the Vacuum train.

On the following day the van was placed in the middle of the train. In this case the first experiment was made with a speed of 50 miles per hour. There was a violent jerk, and the draw-bar of the leading van was torn out, and the train separated from the engine. As the Vacuum is not an automatic brake, the fracture caused the brakes to be taken off the train; the rapid and judicious action taken by those in charge of the engine prevented, however, any serious collision between the engine and the train.

These fractures of couplings appear to have been due to the more powerful and immediate application of the brakes on the engine in these cases as compared with the rate at which the brake-blocks came on at the rear of the train; the buffers were consequently driven home for a time, and then, at the moment when the reaction of the buffer-springs was commencing to have its effect, the brakes at the rear of the train also came into operation; thus a violent, and in the last-mentioned case a successful, effort at separation occurred between the engine and train.

After this accident the experiments were continued with eleven carriages instead of twelve, the van being fifth instead of sixth from the engine. The brake-lever was moved with caution; the e[illegible]ical

GALTON-WESTINGHOUSE TESTS

connection for starting the recording apparatus also acted irregularly, so that the diagrams of these further experiments present great discrepancies between themselves as to the rate at which the pressure came on.

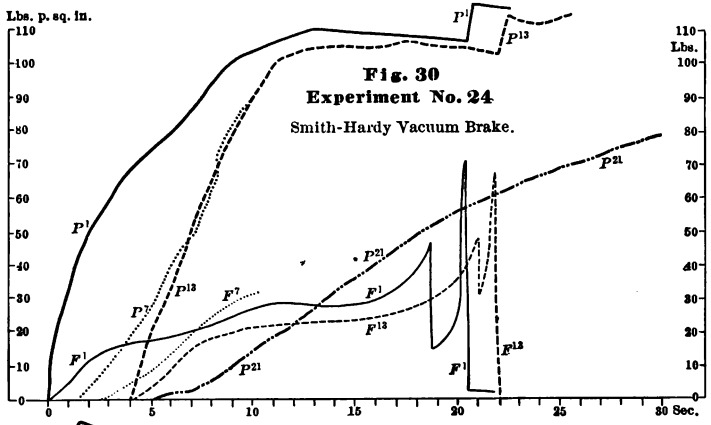

Fig. 30
Experiment No. 24
Smith-Hardy Vacuum Brake.

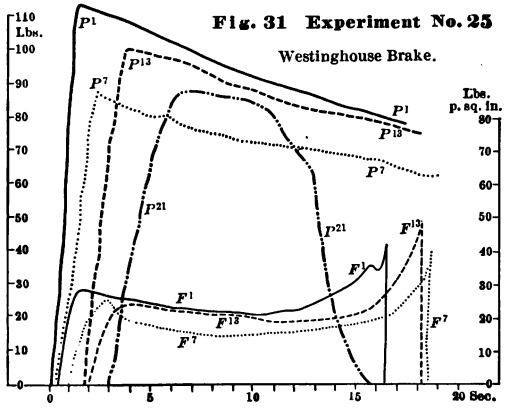

Fig. 31 Experiment No. 25
Westinghouse Brake.

The figures suffixed to the letters *P* and *F* in Figs. 30 and 31 denote the place of the Experimental Van in the train, from the engine.

The author on this account obtained the permission of the North Eastern Railway to repeat these experiments, and the renewed trials took place on the 18th October. On this occasion the recording apparatus was set in motion by the first movement of the brake lever.

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The experiments on the Westinghouse train were partly made by slipping the experimental van and eleven carriages, and allowing the slipped portion to come to rest by the automatic action of the brakes. The experiments on the Vacuum train were a repetition of those of the second day; in the course of the ninth experiment the draw-bar of the second vehicle from the engine gave way.

Figs. 30 and 31 show the results obtained from the two first days' experiments on the North Eastern Railway as to the rates at which the pressures and frictional resistances come into operation in each position of the van in the train; and the accompanying table shows, as nearly as can be obtained from the diagrams, the time which was required after moving the brake-handle to set the brakes with various degrees of force in different parts of the train. The last experiment, where the van was the twenty-first vehicle from the engine, was made with a stationary train of twenty carriages, there being only twelve carriages available on the experimental train.

TABLE VII.—TIME EXPENDED IN PUTTING ON BRAKES.

Place of Experimental Van from Engine.	VACUUM BRAKE.				WESTINGHOUSE AUTOMATIC BRAKE.			
	Commencement of Movement of Blocks.	Half On.	Three-quarters On.	Full On.	Commencement of Movement of Blocks.	Half On.	Three-quarters On.	Full On.
	Seconds	Seconds.	Seconds.	Seconds.	Seconds.	Seconds.	Seconds.	Seconds.
1st Vehicle	½	3	7	11	¼	⅝	¾	1½
7th do. .	2	6½	8½	14	1	1¾	2	2½
13th do. .	3½	7½	9½	14	1¾	2¾	3⅛	3½
21st do. .	5½	17	30	..	3	4½	5	5½

The short time which has elapsed since the above experiments were made has not allowed the author to analyse the results fully for the present meeting. They give, however, a fair approximate indication

of the rate at which the pressure comes on, with these forms of brake, in different parts of a train. It was evident in the course of these experiments that the difference in the rapidity of application in the rear as compared with the front of the train gives rise to jerks and unpleasant motion in the process of stopping, if not to actual danger. They clearly show (as do also the experiments already mentioned on the Brighton Railway) that the perfection of a brake would consist in its application being simultaneous on all the wheels of a train.

The following table gives the particulars of the stops which took place in the experiments of all three days. On the first day the weather was very rainy and disagreeable; on the second day the weather was fine; on the third day the morning was foggy and damp, and the rails very greasy; the afternoon was dry and fine.

TABLE VIII.—STOPS ON NORTH EASTERN RAILWAY.

Vacuum Train.—First Day.

(Van next Engine.)

No.	Speed. Miles per hour.	Distance of Stop. Yards.	Time of Stop. Seconds.	Gradient. R=Rise. F=Fall.	Distance Reduced to 50 Miles per hour. Yards.	Remarks.
1	40	211	..	R 1 in 130 .	329	Heavy rain.
2	35	154	14	R 1 in 130 .	314	do.
3	40	220	17	F 1 in 1200 .	343	do.
4	43	228	17	Level . . .	308	do.
5	49	294	20¼	do. . . .	306	do.
6	35	162	15	do. . . .	330	do.
7	35	154	14½	R 1 in 120 .	314	Broke coupling.
8	49½	316	21	Level . . .	322	
9	53	325	18½	do. . . .	289	Heavy rain.
10	50½	334	21	do. . . .	327	do.
11	35	162	14¾	R 1 in 1200 .	330	do.
12	47½	281	20	F 1 in 130 .	311	do.
13	32	136	13¾	F 1 in 130 .	332	do.
14	28	114	12¾	F 1 in 130 .	376	do.
15	31	136	14	F 1 in 130 .	353	do.

Air Brake Tests

Vacuum Train.—Second Day. (Van in middle of train.)

No.	Speed. Miles per Hour.	Distance of Stop. Yards.	Time of Stop. Seconds.	Gradient. R=Rise. F=Fall.	Distance Reduced to 50 Miles per Hour. Yards.	Remarks.
22	49	440	64½	Level . . .	458	Broke draw-bar of leading van.
23	39	*158	13½	F 1 in 1200 .	259	Fine. Good rail.
26	43	*184	14½	R 1 in 130 .	248	do.
27	37	*132	12¼	Level . . .	241	do.
28	41	*162	13¾	R 1 in 120 .	240	do.
29	50	*246	16½	Level . . .	246	do.
30	55½	*299	18¾	do. . . .	242	do.
31	36	*140	13	F 1 in 130 .	270	do.
32	35	*123	12	F 1 in 130 .	251	do.

* These distances are not reliable, owing to slow action of recording apparatus.

Vacuum Train.—Third Day (repeated experiments). (Van in middle of train.)

No.	Speed. Miles per Hour.	Distance of Stop. Yards.	Time of Stop. Seconds.	Gradient.	Distance Reduced to 50 Miles per Hour. Yards.	Remarks.
7	53	308	19	Level . . .	274	
8	41½	193	14½	do. . . .	280	
9	49¾	255	16½	do. . . .	258	
10	35	145	12¾	do. . . .	296	Fine.
11	57½	356	20	do. . . .	269	Very good rail.
12	57	334	19½	do. . . .	257	
13	57	352	21	do. . . .	271	
14	53	312	19¾	do. . . .	278	
15	35	193	22	F 1 in 130 .	394	Draw-bar broke.

Westinghouse Train.—Second Day.

No.	Speed. Miles per Hour.	Distance of Stop. Yards.	Time of Stop. Seconds.	Gradient.	Distance Reduced to 50 Miles per Hour. Yards.	Remarks.
18	43	180	14	Level . . .	243	Damp, without rain.
19	30	114	12¼	do. . . .	316	do.
20	46	211	15½	do. . . .	249	do.
21	37	140	12½	do. . . .	255	do.
22	35	123	11½	R 1 in 120 .	251	do.
24	56	316	19¼	F 1 in 130 .	251	do.
25	35	132	12	Level . . .	289	do.
26	40	162	14	R 1 in 1200 .	253	do.
27	50	246	17½	Level . . .	246	do.
28	41½	171	14	do. or F 1 in 130	248	do.
29	35	123	12	F 1 in 130 .	251	do.
30	28	88	10	F 1 in 130 .	280	do.

Westinghouse Train.—Second Day.

No.	Speed. Miles per Hour.	Distance of Stop. Yards.	Time of Stop. Seconds.	Gradient. R=Rise. F=Fall.	Distance Reduced to 50 Miles per Hour. Yards.	Remarks.
1	51	281	18¾	Level . . .	270	Fine. Greasy rail.
2	41	184	15	F 1 in 1200 .	273	do.
3	48	215	15½	Level . . .	233	do.
4	30	88	9¾	do. . . .	244	do.
5	36	149	13½	do. . . .	287	do.
6	50	264	18¼	do. . . .	264	do.
7	37½	140	12½	do. . . .	248	do.
8	56	334	20¾	do. . . .	266	do.
9	56	299	19	do. . . .	238	do.
10	38	149	13½	do. . . .	257	do.
11	36	132	12	do. . . .	254	do.
12	31½	110	11¼	do. . . .	277	do.
13	50	255	17¼	R 1 in 1200 .	255	Good rail.
14	40	159	14	Lev. or F. 130	248	do.
15	35	132	12¼	F 1 in 130 .	269	do.
16	32½	96	10½	F 1 in 130 .	227	do.
18	59½	404	23	Level . . .	285	do.
19	59	378	22¾	do. . . .	271	do.
20	45	202	15	do. . . .	249	Signal from driver. Good rail.
21	55	290	19	do. . . .	239	Good rail.
22	50	246	17¼	F 1 in 130 .	246	do. No diagram.

Westinghouse Train.—Third Day. (Van next Engine.)

No.	Speed. Miles per Hour.	Distance of Stop. Yards.	Time of Stop. Seconds.	Gradient.	Distance Reduced to 50 Miles per Hour. Yards.	Remarks.
1	43	228	16	R 1 in 130 .	308	Damp and very greasy rail.
2	58	294	18	Level . . .	218	Eleven carriages and experimental van let slip from engine.
3	57	259	17	do. . . .	199	
4	59	506	27¾	F 1 in 130 .	363	Very greasy rail. Stops made with engine and train.
5	58	378	22	Level . . .	280	
6	55	316	20	do. . . .	261	

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Conclusions.—In conclusion, the author would recapitulate what appear from these experiments to be the essential conditions of a good brake, in addition to other matters not coming immediately within the scope of this inquiry.

1st. The skidding of the wheel, so that it slides on the rail, is altogether a mistake, so far as rapid stopping is concerned.

2nd. The pressure with which the brake-blocks are applied to the wheels should be as high as possible, short of the point which would cause the wheels to be skidded and to slide on the rails.

3rd. The rotation of the wheel is arrested as soon as the friction between the brake-block and the wheel exceeds the adhesion between the wheel and the rail; and therefore the amount of pressure which should be applied to the wheel is a function of the weight which the wheel brings upon the rail. The value of this function varies with the adhesion; hence, with a high adhesion a greater pressure can be applied, and a greater measure of retardation obtained, than with a low one.

4th. In practice and as a question of safety it is of the greatest importance that, in the case of a train travelling at a high speed, that speed should be reduced as rapidly as possible on the first application of the brakes. For instance, a brake which reduces the speed from 60 miles an hour to 20 miles an hour, in say 6 seconds, has a great advantage as regards safety over a brake which would only reduce the speed from 60 to 40 miles an hour in the same time.

5th. The friction produced by the pressure of the brake-block on the wheel is less as the speed of the train is greater; to produce the maximum retardation so far as speed is concerned, the pressure should thus be greatest on first application; and should be diminished as the speed decreases, in order to prevent the wheels from being skidded (or sliding on the rails) in making a stop. It should be added that the coefficient of friction decreases as the time increases during which the brakes are kept on; but this decrease is slower than the increase of the same coefficient due to the decrease of speed; it has therefore little influence in the case of quick stops.

6th. The maximum pressure should be applied to the wheels as rapidly as possible, and uniformly in all parts of the train.

7th. To prevent retardation from the dragging of the brake-blocks against the wheels when the brakes are not in use, care should be taken that the brake-blocks are kept well clear of the wheels (say half an inch) when in a state of inaction.

There are various mechanical questions connected with brakes, such as the desirability of automatic action, and other considerations, which do not enter into the scope of the present inquiry; the special object of which was to ascertain by direct experiment the forces brought into action in applying the brake-blocks to the wheels.

Railway companies, in considering what form of brake is best suited for traffic, must, whilst they give full weight to the mechanical conditions discussed in this paper, also consider the question of the convenience of any particular form of brake, and ascertain its durability and facility of maintenance and repair. It is further clear from the present series of experiments that the universal application of continuous brakes will raise many questions as to the strength of the rolling stock now in use, much of which was constructed originally to meet other conditions of traffic.

In concluding this paper, the author would again apologise to the Institution for its incomplete character: the fact being that the enormous mass of information which has been collected has entailed so much detailed study that he has only been able to bring before the meeting on this occasion the present very incomplete sketch. He hopes on the next occasion to be able to complete his contribution upon this important subject.

He has to repeat his thanks to Mr. Westinghouse for the beautiful apparatus contrived by him; and for the very valuable assistance he has rendered in carrying out these experiments.

He would further beg to tender his best thanks to the Directors of the Brighton Railway Company, and to their able and energetic Manager, Mr. Knight, and their able Locomotive Superintendent, Mr. Stroudley, for their coöperation and assistance in the enquiry,

GALTON-WESTINGHOUSE TESTS

without which it could neither have been commenced nor carried out.

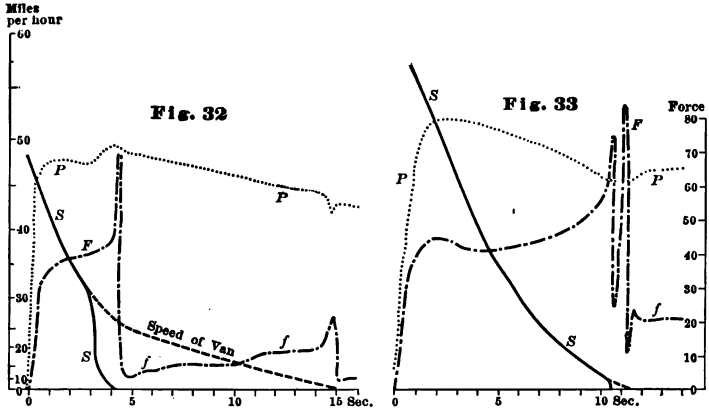
He has also to thank the Directors of the North Eastern Railway Company, and their able Manager, Mr. Tennant, for their courteous assistance in elucidating this difficult subject.

Captain GALTON explained at the close of his paper that the results of the second day's experiments with the vacuum train, given in Table VIII., were practically superseded by those of the third day's experiments, given just after. The distances given in the former case were subject to some question, owing to discrepancies which he had found in the diagrams; and therefore the second table of results should stand instead of the first.

ON THE EFFECT OF BRAKES UPON RAILWAY TRAINS.
(*Third Paper.*)

By Captain DOUGLAS GALTON, C.B., Hon. D.C.L., F.R.S.

In the previous papers upon this subject which the author brought to the notice of the members of the Institution in June and October, 1878, it has been explained that it was anticipated, when the experiments were begun on the Brighton Railway with the van fitted with the self-recording apparatus, that the results would enable a rule to be laid down determining the amount of brake-block pressure, in proportion to the weight of the vehicles, which should be applied to the wheels of railway trains.



Effect of Skidding.

It was immediately discovered, however, that the retarding effect of a wheel sliding upon a rail was much less than when braked with such a force as would just allow it to continue to revolve.

The above copies of two sets of diagrams, Figs. 32 and 33, taken during the experiments, show, more clearly than can be explained, the difference in the retarding force, before the wheels begin to slide upon

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the rails, and after. These two experiments were made with a single van slipped from the engine, the brakes going on automatically at the moment when separation from the engine took place. These and all the other diagrams illustrating this paper are similar to those given in the second Paper. The line S S shows the speed of the braked wheels at each instant, the scale for which is given in miles per hour. The line P P represents the pressure against four blocks acting upon one pair of wheels: the vertical height of P on the scale headed "force," when multiplied by 240, gives the total pressure in pounds on the four blocks collectively. The line F F shows the retarding effect of the four blocks upon the one pair of wheels before the wheels began to slide upon the rails; and *f f* shows the effect while the wheels were sliding upon the rails. The vertical height of F or *f* on the scale of force, multiplied by 60, gives the total retardation in pounds upon that pair of wheels.

The calculations show that the friction between the wheel and the rail, when the wheel is sliding on the rail, is *less than one-third* of the friction produced between the brake-blocks and the wheel, when the brake-blocks are so applied as to allow the wheel to continue revolving.

Coefficient of Friction as affected by Speed.

The next important discovery was, that the coefficient of friction between the brake-blocks and the wheels varied inversely according to the speed of the train, a higher proportion of brake-block pressure to weight being required at high speeds, and a lower pressure for a lower speed. This was illustrated by the diagrams shown in Figs. 16, 17, 19, 20 of the second Paper.

Table I. given in the second Paper for the values of this coefficient at different speeds has since then been somewhat altered by obtaining a mean from a considerably larger number of experiments. The accompanying Table IX. shows the altered result.

Coefficient of Friction as affected by Time.

If the friction of the brake-blocks were always the same at the same speed, some simple rule might still be deduced which would give the

pressure required at each speed for obtaining a certain amount of retardation; but when the speed of the van was kept nearly uniform by the effort of the engine, the friction of the blocks *decreased;* and this occurred notwithstanding a continued increase of the brake-block pressure: showing that, through some cause not yet fully determined, the holding power of brake-blocks at all speeds is considerably less after some seconds of application then when first applied. This peculiarity is illustrated by Figs. 16, 17, 18 of the second Paper. Hence the question of the proper amount of brake force needed at each instant, during the time required to stop a train, is still further complicated by this decrease which occurs in the coefficient of friction after the brakes have been applied, and which results from the time during which

TABLE IX.—COEFFICIENT OF FRICTION AT VARYING SPEEDS. CAST-IRON BRAKE-BLOCKS ON STEEL TIRES.

Number of Experiments from which the Mean is Taken.	Velocity.		Coefficient of Friction.		
	Miles per Hour.	Feet per Second.	Extremes Observed. Maximum.	Extremes Observed. Minimum.	Mean.
12	60	88	.123	.058	.074
67	55	81	.136	.060	.111
55	50	73	.153	.050	.116
77	45	66	.179	.083	.127
70	40	59	.194	.088	.140
80	35	51	.197	.087	.142
94	30	44	.196	.098	.164
70	25	36½	.205	.108	.166
69	20	29	.240	.133	.192
78	15	22	.280	.131	.223
54	10	14½	.281	.161	.242
28	7½	11	.325	.123	.244
20	Under 5 Just moving	Under 7 Just moving	.340	.156	.273
			. . .	. . .	.330
Fleeming Jenkin (steel on steel)		.0002 to .0086	.337	.365	.351
Rennie. *Static Friction* under Pressure of 180 lbs. per square inch					.300
Pressure of 336 lbs. per square inch					.347

GALTON-WESTINGHOUSE TESTS

they are kept applied, irrespective of any change in speed. This decrease in the coefficient of friction was shown in Table I. of the second Paper, from which the following figures are taken :—

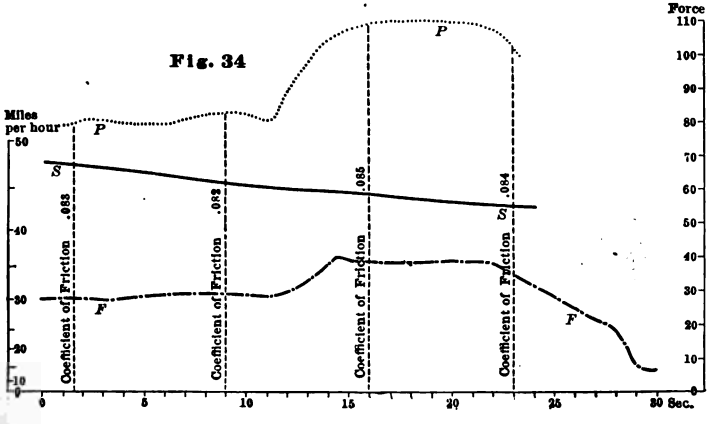
TABLE X.—COEFFICIENT OF FRICTION AS AFFECTED BY TIME.

SPEED.	COEFFICIENT OF FRICTION.				
Miles per Hour.	Commencement of Experiment.*	After 5 Seconds.	After 10 Seconds.	After 15 Seconds.	After 20 Seconds.
20	.182	.152	.133	.116	.099
27	.171	.130	.119	.081	.072
37	.152	.096	.083	.069	
47	.132	.080	.070		
60	.072	.063	.058		

* The figures in this column are somewhat different from those that have just been given in the altered Table IX., because they resulted from the average of fewer experiments; but the effect of time in reducing the coefficient of friction may be accepted as correct.

The decrease in the coefficient of friction arising from time sometimes overcomes the increase in the coefficient of friction arising from a decrease in speed, especially when, either from the stop being on a descending gradient or from a small proportion of the train only being

Fig. 34



fitted with brake power, the train takes a considerable time in coming to rest. Therefore a higher brake pressure is required in such cases than when the stop is made in a short time.

The accompanying diagram, Fig. 34, shows a uniform coefficient of friction with a practically uniform speed, as obtained by means of an increasing brake-block pressure. The line P P shows the pressure, F F the friction (the coefficient of which is given for several ordinates), and S S the speed, which latter decreased slightly during the experiment, and would have caused an increase in the coefficient of friction had it not been counteracted by the element of time.

Coefficient of Friction affected by Material and Weather.

On experimenting further, it was found that the coefficient of friction was also influenced by the kind of metal in the blocks, and by the state of the weather.

Experiments on a Train cannot be free from Disturbing Elements.

The experiments were made upon trains travelling under conditions which of necessity were continually varying, and therefore presented many elements of disturbance beyond the reach of calculation.

The time during which the pressure was applied has been shown to enter largely into the question, and this element of disturbance is in operation during the interval of time (however short) which necessarily occurs between the moment when the block first touches the wheel and the moment when the full pressure is obtained.

Under these circumstances the author has limited himself to stating the facts obtained in the experiments, and has refrained from endeavouring to lay down the law of decrease in the coefficient of friction according to velocity; as he believes that any law which could be laid down would only tend to mislead, owing to the continually varying conditions which occur in practice.

The Institution of Mechanical Engineers has decided to carry on through the medium of their Research Committee further experiments on this very interesting subject; and if these new experiments can be

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arranged so as to be free from the disturbing elements incidental to those which he has had the opportunity of making, the author trusts that the question will soon receive fuller elucidation.

Adhesion as affecting the Maximum Retardation.

Notwithstanding the variations in the coefficient of friction between the blocks and wheels, it was found that under similar circumstances the adhesion of the wheels to the rails was practically constant, but that it varied according to the material — that is, whether the train was travelling upon iron or steel rails; and according to the state of the rails, whether dry, wet, or sanded.

On dry rails it was found that the coefficient of adhesion of the wheels was generally over .20. In some cases it rose to .25 or even higher. On wet or greasy rails, without sand, it fell as low as .15 in one experiment, but averaged about .18. With the use of sand on wet rails it was above .20 at all times; and when the sand was applied at the moment of starting, so that the wind of the rotating wheels did not tend to blow it away, it rose up to .35, and even above .40.

The retarding force which causes a train to be stopped by the application of brakes is limited to the adhesion or resistance obtained between the wheel and the rail; therefore the greatest effect in stopping a train is produced when the friction between the brake-blocks and the wheel amounts to a quantity just short of the adhesion; because as soon as the brake-block friction exceeds the adhesion, the wheel becomes fixed and begins to slide.

If a certain amount of brake force or brake-block pressure would produce an equal amount of friction at all speeds, then the greatest possible amount of retardation during the time required to make a stop could easily be obtained; but, as has already been proved, the brake pressure at high speeds must be much greater than at low speeds, in order to produce the same amount of retardation.

The friction increases as the speed decreases, according to some law, which is complicated, as shown above, by the time during which the brakes have been applied. If therefore the pressure necessary to cause

sufficient friction to balance the adhesion at a high speed be continued till the train comes to rest, the friction will increase and gradually overcome the adhesion, and the wheels will become fixed. This is illustrated by Fig. 19, page 51.

Therefore, in order to secure the best results in stopping, it is obviously necessary that the brake-block pressure should be so regulated as to give a friction about equal to the adhesion of the wheels at every stage during the process of stopping.

Regulator for Brake-block Pressure.

In some of the former experiments on the Brighton Railway a pressure-reducing valve was introduced by Mr. Westinghouse, with the view of reducing the brake-block pressure as the speed was reduced; and excellent results were obtained. And it will be recollected that the author, in his last paper, pointed out the possibility of devising some self-acting apparatus whereby the friction between the blocks and wheels should actually regulate the pressure put upon the blocks, and keep it at the precise amount required.

Mr. Westinghouse has since devised a new valve, so arranged in connection with one of the brake-blocks that the friction between the block and wheel regulates the pressure upon the blocks. The author had the opportunity of making some experiments on the Brighton Railway on 20th January, 1879, for the purpose of testing this new valve. These experiments are very interesting, as tending to elucidate this part of the subject. The valve, as then used for the first time, was found to regulate the pressure of the brake-blocks against the wheels, and to reduce the pressure as required, except at the last moment, when the escape port was incapable in some cases of discharging the air fast enough to prevent skidding for a very short distance. It was also found that there was a needless waste of air from the reservoir. From the experience gained, a slight alteration has been made, which obviates the above difficulties.

The general arrangement of the regulating valve as applied to railway carriages is shown in Fig. 35; Figs. 36 and 37 are

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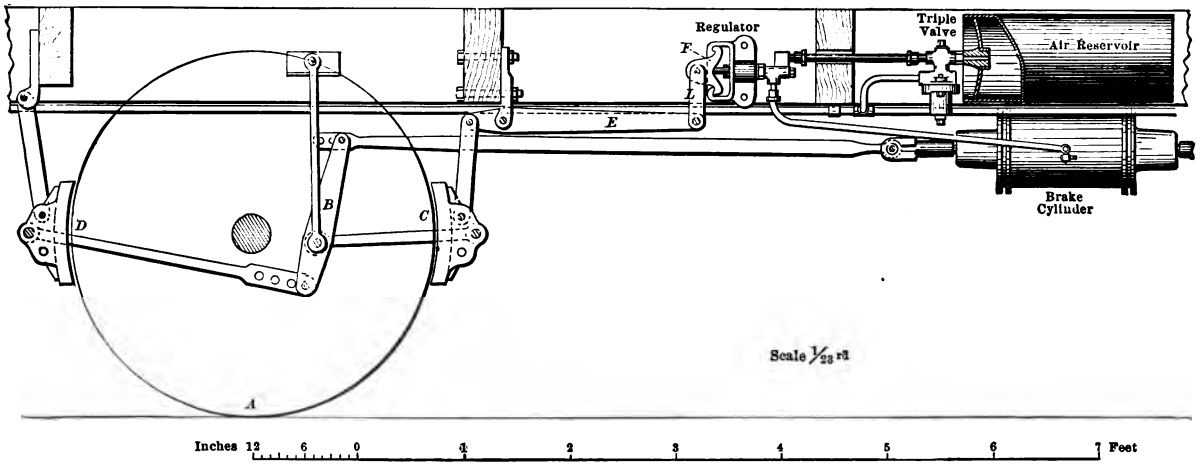
General Arrangement of Brake Gear with Friction-Regulating Valve.

Fig. 35



enlarged sections of the valve itself, the first in the normal condition when it is closed, and the second when it is opened to reduce the pressure. In order to understand the action of the valve, suppose that four blocks act against a pair of wheels, the load at A (Fig. 35) on the two wheels being 10,000 lbs. The lever B is of such a proportion that the block C has 3 lbs. pressure upon it for every 2 lbs. on the block D. If the coefficient of adhesion at A is .20, the total adhesion is equal to 2,000 lbs. for the two wheels, or 1,000 lbs. for each wheel. If the rotating momentum of the wheels be taken as equivalent to an increase of $\frac{1}{10}$ of the weight at A, then the four brake-blocks will have to offer a resistance of 2,200 lbs. to the two wheels, or 1,110 lbs. to one wheel, in order to obtain a result equal to .20 of the load at A. If the friction of the blocks C and D on one wheel together equals 1,100 lbs., then, owing to the proportion of pressure upon them, the resistance offered by C will be 660 lbs., and by D 440 lbs. The block C is suspended from one end of a lever E, the opposite end of which, acting through a link L, tends to move one or other arm of the double bell-crank lever F. The form of this lever F provides for the rotation of the wheel in either direction. The lever E has a proportion of 6¾ to 1, and consequently requires 97.7 lbs. at its long end, to equal 660 lbs., the assumed friction of the block C.

The motion of the lever F, Figs. 36 and 37, is resisted by the bolt G and spring H. When, however, the force on the link L is sufficient to move the bolt G and compress the spring H, a plug valve J in a case K is moved by the bolt. This valve communicates with the triple valve and air-reservoir by the pipe P, and with the brake-cylinder by the pipe M; while N N are openings to the external air. When the regulating valve J is closed (Fig. 36) these openings are shut, and the passage from the reservoir to the brake-cylinder is open; but when the valve J is pushed inwards by the bolt G, it first closes the passage of air from the reservoir to the brake-cylinder, and, then, if moved slightly further, it opens the passage from the brake-cylinder to the atmosphere, thereby reducing the pressure of the air in the brake-cylinder, according to the area of the passage and the time during which it is kept open.

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Enlarged Sections of Friction-Regulating Valve.

Fig. 36

Air Outlet closed.

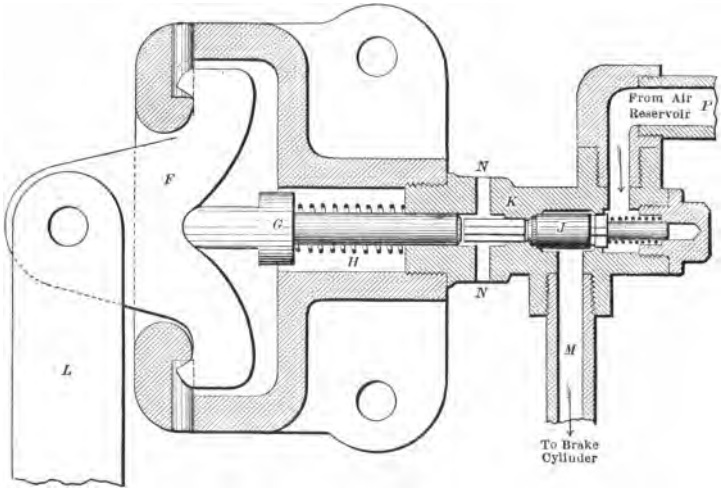
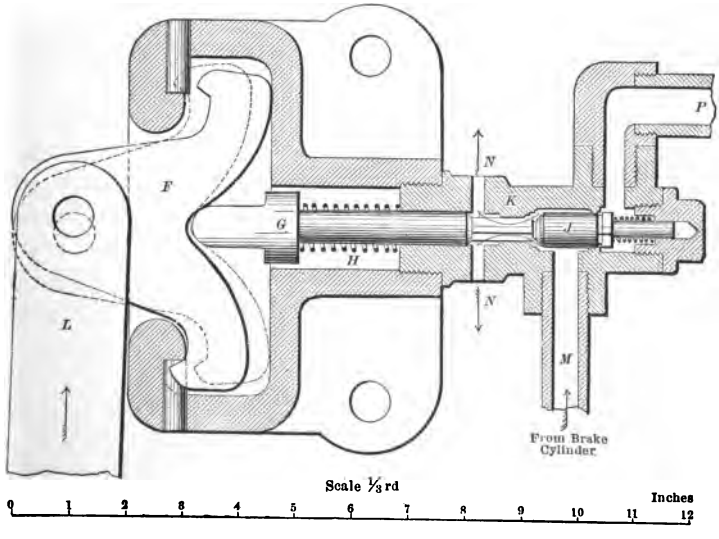


Fig. 37

Air Outlet open.



Scale ⅓rd

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The spring H alone offers 75½ lbs. resistance to compression, which is equivalent to a coefficient of adhesion of .15 between the wheel and the rail. The regulating valve J has slightly over .3 sq. in. area, and if acted upon by an air pressure from the reservoir of 75 lbs. per sq. in. it gives an additional resistance of 22½ lbs., making a total resistance of 98 lbs., equivalent to a coefficient of adhesion of .20. If a pressure of only 37½ lbs. per sq. in. be admitted to act upon the valve J, the total resistance against the lever E will be only 86.6 lbs., equivalent to a coefficient of adhesion of .175. Thus it will be seen that by simply regulating the air pressure in the reservoirs under the carriages, a considerable variation in the resistance can be made according to the state of the rails. One of these regulating valves is put on each carriage, and the spring H and valve J are alike in all.

The lever E must be proportioned according to the load at A; and with the arrangement of brake levers and blocks shown in Fig. 35, the long end will be to the short end as 1½ to 1 for a load of 1 ton on each pair of wheels, or as 7½ to 1 for a load of 5 tons. If the brake levers and blocks were not arranged as shown, the proportion of the lever would have to be altered, so that the actual amount of resistance on the short end should give 98 lbs. pressure on the long end. It is essential in the use of this regulating valve, if one valve is to operate for the whole carriage, that the brake gear should be so arranged that any one block can act as a fulcrum for all the others. By this arrangement it becomes a simple matter so to regulate the brake pressure as to produce a definite maximum amount of brake resistance; the amount thus fixed should equal the highest average amount required.

The regulating valve can thus be arranged so as to prevent the skidding of the wheels: and by the fact that it closes the passage for the air from the reservoir to the brake-cylinder before it allows any escape of air from that cylinder to the atmosphere, it possesses the property of permitting a high working pressure to be constantly maintained in the reservoir, without the danger of ever getting too high a pressure in the brake-cylinder. At the same time, if, after the valve has been opened

TABLE XI.—EXPERIMENTS MADE WITH THE FRICTION REGULATOR.

Diagrams shown in Fig.	No. of Experiment. No.	Gradient. R=Rise. F=Fall.	Speed. Miles per Hour.	Time of Stop. Seconds.	Length of Stop. Yards.	Distance Reduced to 50 Miles per Hour. Yards.	Total Brake-block Pressure P on the Four Wheels. Maximum. Lbs.	Middle of Experiment. Lbs.	End or at Skid. Lbs.	Percentage of Brake-block Pressure to Weight on Wheels. Maximum at Commencement of Experiment.	Minimum at End of Experiment.	Observed COEFFICIENT OF FRICTION between Brake-blocks and Wheels. At Moment when Maximum Pressure was Obtained.	At Middle of Experiment.	At End of Experiment.	Mean Retardation Calculated from Stop. Percentage of Weight on Wheels.
	3	Level	53	13	171	152	26,910	25,350	25,350	133	125	.177	.184	Skid	18.3
38	4	R 1 in 264	60	12	171	118	32,370	31,200	23,010	160	114	.129	.125	.241	23.3
42	5	R 1 in 311	60	12¼	167	116	32,760	30,810	29,250	162	145	.145	.161	Skid	23.9
	8	Level	55	13	195	161	27,690	26,910	26,130	137	129	.147	.132	do.	17.2
	9	do.	60	14¼	214	148	28,470	26,520	23,790	141	118	.119	.166	do.	18.7
39	10	R 1 in 264	57	15	206	158	23,010	20,280	10,920	114	54	.141	.158	.312	17.4
40	11	F 1 in 264	55	12	171	141	28,860	26,910	21,450	143	106	.155	.170	Skid	19.7
	12	R 1 in 330	55	10½	141	116	28,470	27,690	16,380	141	81	.160	.176	.31	23.8
41	15	Level Last 30 yards F 1 in 176	55	18	227	194	17,550	14,430	8,190	87	40	.161	.182	.309	14.3
	16	F 1 in 406	57	18½	223	171	24,570	15,990	7,800	122	39	.157	.158	.35	16.8

to the atmosphere, an increased pressure on the brake-blocks is again required in order to compensate for the diminution of friction owing to lapse of time or to other causes, the decreasing friction will allow the valve to close the escape orifice from the brake-cylinder and reopen the connection to the air reservoir; it will thus replenish the cylinder with the original high pressure of air, which may be again reduced and again restored by the valve, as may be required.

Experiments made with the Friction Regulating Valve.

The preceding Table XI. shows several of the experiments made on 20th January, 1879, by slipping the experimental van from the

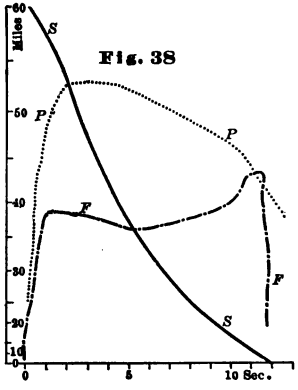

Fig. 38

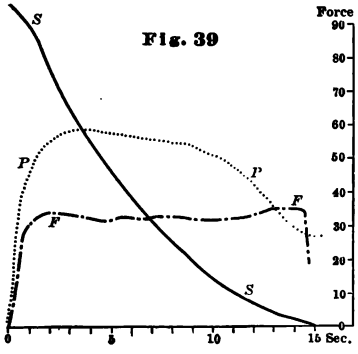

Fig. 39

engine and bringing it to rest by means of the brake applied to all four wheels.

The diagrams, Figs. 38 to 42, which have been selected from the experiments shown in Table XI., sufficiently illustrate the action of the regulating valve. These diagrams show also very clearly the variation in the coefficient of friction according to speed.

In the experiment, Fig. 38, the van was stopped from a speed of 60 miles per hour in 12 seconds on a rising gradient of 1 in 264. The maximum brake-block pressure on all the four wheels was 160 per cent. of the weight on the wheels at the beginning, and was reduced to 114 per cent. at the end. The friction increased toward the end of the

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experiment so much as to cause the wheels to skid just at the end. The adhesion shown was about .25. In this case the pressure was not reduced sufficiently to keep the friction uniform.

Had this stop been made on a steep descent, or had the brake-blocks been acting on only one pair of wheels, the time required to effect the stop would have been greater; and consequently the brake-block pressure, instead of being reduced, must have been increased, so as to overcome the decrease in the holding power of the blocks which results from the length of time of application irrespective of the speed.

In the experiment, Fig. 39, the van was stopped from a speed of 57 miles an hour on a rising gradient of 1 in 264 in 15 seconds. In this

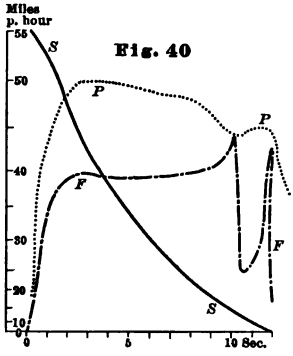

Fig. 40

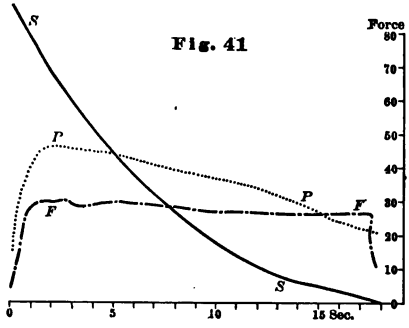

Fig. 41

case the brake-block pressure was 114 per cent. of weight on wheels at the beginning of the experiment, and was reduced to .54 per cent. towards the end. The total friction of the brake-blocks on the four wheels may be estimated, from the actual friction obtained for one pair of wheels, at 3,244 lbs. at the beginning of the experiment, and 3,144 lbs. in the middle, thus remaining very nearly constant; and it slightly increased to 3,400 lbs. towards the end. There was no skidding; but the greater length of time occupied in the stop shows that the pressure was not sufficiently high at the beginning.

Fig. 40 shows a stop from a speed of 55 miles an hour in 12 seconds, on a falling gradient of 1 in 264. The brake-block pressure

at the beginning of the experiment was 143 per cent. of weight on wheels, and was reduced to 106 per cent. at the end. The resulting friction as estimated for the brake-blocks on the four wheels is 4,473 lbs. at the beginning, and 4,574 lbs. in the middle of the experiment, after which, as the pressure was not reduced with sufficient rapidity, it rose rapidly, and caused a skid at the end. The adhesion shown was about .25. In this case the stop made was much better than that shown in Fig. 39, because of the greater initial pressure and greater consequent friction.

Fig. 41 also illustrates this point by showing a stop from a speed of 55 miles an hour on a level in 18 seconds. The brake-block pressure was 87 per cent. of weight on wheels at the beginning, and 40 per cent. at the end; and the consequent estimated friction was only 2,825 lbs. at the beginning, and 2,530 lbs. at the end; consequently a longer time was required for making the stop.

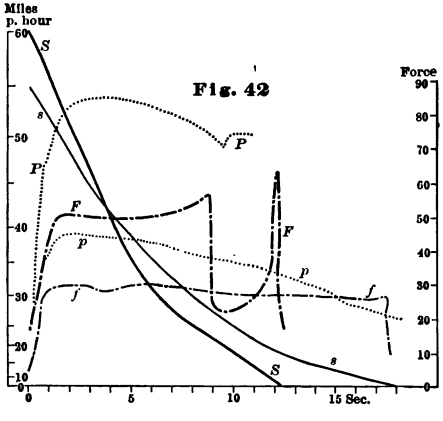

Fig. 42

Fig. 42 further illustrates the necessity of a high pressure on the first application of the brakes, if a rapid stop is to be effected. The heavy lines show the speed S, pressure P, and friction F, in a stop made from 60 miles an hour on a rising gradient of 1 in 311. The brake-block pressure was 162 per cent., or nearly two-thirds more than the weight on the wheels at the beginning of the experiment, but it was not reduced with sufficient rapidity; hence one pair of wheels skidded at the end of 9 seconds, at which time the speed was reduced to about 17 miles per hour; and, notwithstanding this skidding, the van came to rest in 167 yards and in 12¼ seconds. The light lines give the speed *s*, pressure

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p, and friction f of the stop shown in Fig. 41; and it will be seen that from an initial velocity of 55 miles an hour, and with a maximum brake-block pressure of about 87 per cent. of weight on wheels, the speed at the end of nine seconds had only been reduced to about 27 miles per hour, and that the van came to rest in 227 yards and in 18 seconds.

The object of the regulating valve was to obtain a uniform brake-block friction during the whole progress of the stop, and to give to this friction the highest admissible value, *i. e.*, a value as nearly as possible equal to the adhesion of the wheels upon the rails, and therefore just short of that which could cause the wheels to skid. It will be seen from the diagrams that the rapidity of the stop varied according to the greater or less approach made towards the attainment of this object, the resistance of the valve itself being purposely altered during the progress of the experiments.

The conditions for these stops were very favorable, and indicate an adhesion of the wheels upon the rails in excess of the average obtainable; which average, throughout 300 experiments, slightly exceeded .18 of the weight on the wheels.

These experiments were made with the one van alone, without any carriages attached to it. Since making them the author has had the opportunity of making slip experiments on the Paris, Lyons & Mediterranean Railway with twelve carriages attached to the van (see page 111). The average of seven stops reduced to 50 miles an hour was 203 yards, with only 63 per cent. of the weight of the train braked. If brakes had been applied to all the wheels of the train, as was the case in the experiments with the single van, the result would have been 128 yards from 50 miles an hour, or a very close approach to the best results obtained with a single vehicle. The author has not had time to analyse these latter experiments fully; but he is able to state that they demonstrate that the stops which have been obtained with a single vehicle may also be obtained with a train of several vehicles.

Regulation of Pressure necessary for a perfect Brake.

The regulating valve here described is an outcome of the former experiments on this subject; and is proposed for the purpose of preventing the sliding of the wheels on the rails. Some such device is a necessary adjunct to a perfect brake, because it is only by the prevention of skidding that the maximum of efficiency can be obtained; whilst, in addition, skidding damages both wheels and rails, and increases the risk of accident. But the previous illustrations show that, however perfect any apparatus of this description may be, and however certainly it may act to prevent skidding, yet, owing to the very numerous conditions which affect the application of brakes, it is necessary, if at the same time the maximum allowable friction is always to be exerted on the wheels so as to insure the best result in stopping, that the action of the apparatus should be capable of being regulated from time to time, so as to meet the varying conditions as to adhesion, etc., of the line on which it is travelling; unless indeed some arrangement could be made by which the actual adhesion at the moment could be brought into play to regulate the pressure.

Momentum of Wheels due to Rotation.

In dealing with this subject the author has not hitherto directed attention to the question of the influence of the rotating momentum of the wheels, but he now wishes to state what he has observed on this point. Usually there are in a train a certain number of vehicles braked and a certain number unbraked. When the brakes act on all the wheels, then the rotating momentum of the wheels does not add to the distance in stopping the train, because that momentum can be acted upon by the brakes directly, without in any way making use of the adhesion of the wheels upon the rails. It simply requires, therefore, an additional amount of brake-block pressure, and if a regulating valve be used, an increase in the resistance of the regulating valve to compensate for this rotating momentum.

With the unbraked portion of a train, the rotating momentum of the wheels is an addition to the momentum due to the weight of the train

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(including therein the actual weight of the wheels), which addition cannot be utilized for retardation; and it therefore seems the more important that there should be brakes on every wheel of a train.

Relation between the Retardation applied and the Weight of Train.

The following Table XII. shows the distances run in stopping a train on a level from a speed of 50 miles per hour, with a retarding force varying from 5 to 30 per cent. of the total weight of the train:

TABLE XII.—RETARDING FORCES AND STOPS.

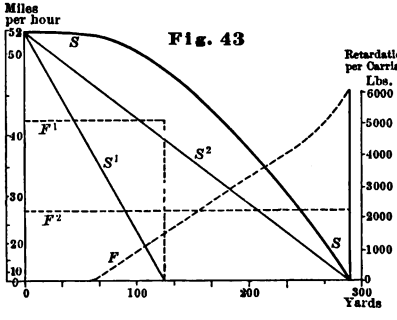
Retarding Force in Proportion to Weight of Train. Per Cent.	Length of Stop from 50 Miles per Hour. Yards.	Retarding Force in Proportion to Weight of Train. Per Cent.	Length of Stop from 50 Miles per Hour. Yards.
5	555⅔	18	154⅓
6	463	19	146⅓
7	369⅔	20	139
8	347⅓	21	132⅓
9	308⅔	22	129⅔
10	277⅔	23	120⅔
11	252⅓	24	115⅔
12	231⅓	25	111
13	213⅔	26	107
14	198⅓	27	103
15	185	28	99⅓
16	173⅔	29	95⅔
17	163½	30	92⅔

If the brakes act upon every wheel, then a retardation of 10 per cent. of the load carried by each wheel — counting the rotating momentum as part of the weight — will stop a train in 277⅔ yards. If the brakes act upon only half the weight of a train, a retardation of 20 per cent. would have to be exerted upon the braked half to produce the same result. As already pointed out, 20 per cent. adhesion is rather above the average obtainable, while 24½ per cent. is the highest result obtained under the most favorable circumstances at any considerable speed, or except when sand was applied to wheels moving slowly.

The above Table XII. should be carefully noted, for it will be seen that, even when brakes act upon all the wheels, 24½ per cent. re-

tardation will only give 26 yards better result than 20 per cent., or 52 yards if only half the train be braked. If compared with 18 per cent., the average adhesion obtainable, the advantage will be only 41 yards for the train braked throughout, and 82 yards for the train having brakes acting upon half of the weight.

A consideration of this feature of the brake problem points out — 1st, that the advantage to be gained by trying to obtain above 20 per cent. retardation on each wheel is greatly overbalanced by the risk of skidding; and 2d, that it is far easier and safer to make a stop in 250 yards from 50 miles per hour with the whole train braked than with brakes upon only half of the train. All of this points to the fact that in arranging valves for regulating the brake-block friction care should be taken not to exceed a safe limit of adhesion; for in the effort to get more work, less may be the result.



Too much stress cannot be laid upon the importance of immediately applying the full pressure of the brake-blocks against the wheels, and of making the application simultaneous against all the wheels of the train; for any loss of time seriously impairs the efficiency of the brakes in several ways, as has been already explained, independently of the actual increase of distance run in the stop.

In illustration of this point, the diagrams shown in Figs. 43 and 44 are added. Fig. 43 shows the result of an experiment made on 23d August, 1878, in which the application of the pressure was gradual, so as to represent the effect of a slowly-acting brake; it furnished a diagram of a stop nearly identical with one of the best stops made by the Vacuum experimental train on the North Eastern Railway in October last. The curved lines S and F represent the speed and retardation obtained in the experiment; and the straight lines S^1 and

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F^1 the comparative results which would have been obtained if the full pressure had been applied at once, and if the consequent friction had been generated at once between the brake-blocks and wheels, and if this friction had been maintained at a uniform amount. In the latter case the stop would have been made in 125 yards, instead of 287 yards, the actual distance. The straight line S^2 shows a stop which might have been made in the same distance of 287 yards, if the very moderate retardation indicated by the dotted line F^2 had been applied at once. It will be noticed that this stop is much better than the actual stop, though no shorter in distance, because at any intermediate point the speed is much lower; hence at 100 yards, for instance, the energy left in the train, as shown by the straight line

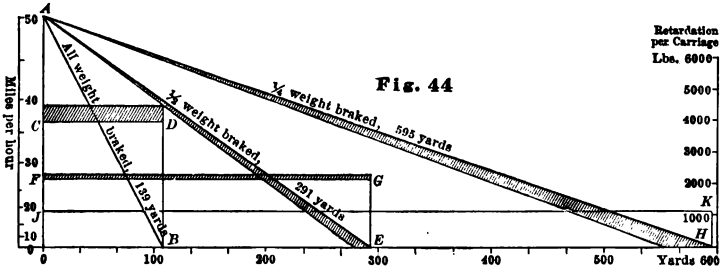

Fig. 44

S^2, is only three-fifths of that shown by the curved line S representing the actual stop.

Fig. 44 illustrates the advantage of applying the brakes to every wheel of a train.

The diagonal line A B indicates the stop which a train could make from 50 miles an hour with the retardation of .20, shown by the horizontal line C D, if applied to every wheel in the train. The shaded area below C D shows the extra retardation consumed in overcoming the momentum of the braked wheels.

The diagonal line A E shows the stop which a train could make from the same speed with the same retardation of .20 applied to only half the wheels and half the weight of the train, as indicated by the horizontal line F G. The shaded area below F G shows the extra retard-

ation consumed in overcoming the momentum of the braked wheels; and the shaded area below A E shows the extra distance run by the train in consequence of the momentum of the unbraked wheels.

The diagonal line A H shows the stop which a train could make from the same speed with the same retardation of .20 applied to only one-fourth of the wheels and one-fourth of the weight of the train, as indicated by the horizontal line J K. The thickness of the line J K and the diagonal shaded area below A H show respectively the extra retardation consumed in overcoming the momentum of the braked wheels, and the extra distance run by the train in consequence of the momentum of the unbraked wheels.

Requirements of a perfect Brake.

Having thus summed up the facts obtained from the experiments which he has made, the author will now add a few observations as to what appears to him still to be necessary in order to complete the investigation in a practical manner for the benefit of the railway companies and the public.

The final solution of the vexed question of continuous brakes can only be brought about by a consideration of the subject in the light of a scientific and practical comparison between the various systems that have been brought into use. But before comparing these various brakes, it is necessary to consider what a perfect brake should accomplish.

A train, through the effort of the locomotive, slowly accumulates energy; and for each ton of weight in the train the accumulated energy is equal to 120 foot-tons at 60 miles per hour, 53 foot-tons at 40 miles per hour, and 13 foot-tons at 20 miles per hour. Thus for a train of fifteen vehicles, weighing 200 tons, the energy at 60 miles per hour is equal to 24,000 tons falling a distance of one foot; or approximately to the energy of a shot from the 80-ton gun.

After a train has attained the desired speed, the reasons for stopping it may be of two kinds: 1st, at prearranged places for convenience;

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and 2nd, for the prevention of accidents, or for mitigating the consequences if accidents are unavoidable.

To stop a train for the first reason requires but a limited amount of force, which may be applied in any crude manner.

For the prevention of accidents, however, there is required :—

(*a*) The instantaneous application of the greatest possible amount of retarding force.

(*b*) The continuous action of this force until the energy of the train is destroyed.

The retarding force now used in practice is that due to the friction resulting from the forcible application of metal or wood brake-blocks to the tires of the wheels ; this friction impedes the rotation of the wheels, and tends, through the adhesion of the wheels upon the rails, to destroy the energy stored in the train. The retarding force is therefore limited to the adhesion available between the wheels and rails. The greatest possible amount of retarding force can thus be obtained only by applying brake-blocks to *every* wheel in the train, *each* block being pressed with sufficient force to produce a resistance to the rotation of the wheel just equal to the greatest possible friction between the wheel and the rail. This greatest possible friction occurs when the adhesion of the wheel to the rail is just about to be overcome by the superior effort of the brake-blocks, which effort, if further increased, immediately begins to stop the rotating movement of the wheel, and thus causes it to slide upon the rail. When a wheel slides upon the rail, its retarding effect is most materially lessened, as has been fully demonstrated above.

The necessity for the instantaneous application of the maximum brake-block pressure throughout the train is so evident, that it is only necessary to call to mind that, at a speed which is frequently attained, namely 60 miles per hour, a train passes over 88 feet in each second.

From the foregoing it will be seen that, in order to stop a train in the shortest possible distance, it is necessary :

1st. That the brake-blocks should act upon every wheel in the train.

2nd. That they should be applied with their full force in the least possible time.

3rd. That the pressure upon them should be regulated according to speed and other circumstances, so that the friction shall nearly equal, but never exceed, the adhesion of the wheels upon the rails.

As it is solely for the object of preventing accidents, or of mitigating the consequences if accidents cannot be avoided, that the use of powerful brakes is urgently required, it becomes necessary to consider next the arrangements which this object necessitates.

In the greater number of accidents the driver is the first to perceive danger, and he should therefore have the power of applying the brakes.

The guards, however, who may be the first to discover the necessity for stopping, either when the driver fails to notice a signal at danger, or from other sufficient cause, should also have power to stop the train, even against the efforts of the driver.

Should a train separate into two or more portions, the brakes should instantly act without the intervention of anyone, and should bring every portion of the train to a stand.

If a carriage or even one pair of wheels should leave the rails, then also should the brakes be applied by the very act of the wheels leaving the rails.

Should the brake apparatus of one or more carriages be destroyed after the commencement of the accident, while the speed yet remains considerable, the brakes upon the other carriages should not be rendered inefficient.

It has been found that, although brakes are mostly intended for the prevention of accidents, they are also useful for ordinary stoppages, and effect a considerable saving of time. The use of continuous brakes moreover enables the number of guards and brakesmen in a train to be reduced. This use, however, becomes a source of danger, if from any cause the brakes fail to act when wanted; hence the necessity for so constructing the brake apparatus that a failure of any essential part shall lead to the instant application of the brakes without the intervention of anyone: a principle which has been proved to be absolutely necessary in the working of the block system.

Air Brake Tests

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As any one vehicle may become separated from the others, it follows that if the brake-blocks are to be applied by the separation of a train, each vehicle must have not only its own brake blocks, but also its own store of power to bring them into operation.

As the speed of 60 miles per hour may be, and often is, attained by fast trains, the maximum force with which the brake-blocks can be pressed against the wheels of each vehicle in such trains should be at least one-and-three-quarter times the weight of the vehicle on those wheels; and even for slower trains the effect of steep declivities must be considered, which is to add to the weight and momentum of the train to be retarded by the brakes, whilst it does not add to the adhesion of the wheels.

The instantaneous and simultaneous application of the brakes to every wheel of a train would seem, so far as the author's experiments show, to be at present impossible; but on a train of fifteen carriages the brakes can be fully applied with an average delay of less than two seconds, and therefore the average time for the full application of the brakes may be fixed at two seconds.

Accepting the foregoing propositions as indisputable, a perfect continuous brake should comply with the following conditions for the prevention of accidents:—

1st. It should be fitted to act upon each wheel of the engine, tender, and every other vehicle in a train of any length.

2nd. However brought into action, it should be capable of exerting upon the blocks of each pair of wheels, within two seconds, a force of twice, or at the very least one-and-three-quarter times, the load on those wheels.

3rd. The brake-block pressure acting on each wheel should be so regulated that the friction between the brake-blocks and the wheel may always be limited so as not to exceed the adhesion between the wheel and the rail; by which means it will produce the maximum effect at each moment of its application.

4th. The brake-block pressure should be capable of being applied by engine-driver or by guards.

5th. The engine, tender, and vehicles should each carry their own store of brake power, which should be independent of the brake power on any other vehicle.

6th. The brake-block pressure should be automatically applied to every vehicle by the separation of the train into two or more parts ; and it should also be applied by a pair of wheels or a carriage leaving the rails.

7th. The brake-block pressure should be automatically applied by such failure of the connections or appliances as would render it afterwards incapable of application until the failure had been remedied.

8th. The brake-block pressure should be capable of application with any degree of force up to the maximum ; and it should be capable of continued action on inclines, or of repeated applications at short intervals at junctions and stations.

In addition to these requirements, the questions of cost, durability, convenience in operation, and other essential points, will, of course, come under consideration.

In preparing the way for a comparison of the various brakes now in use, one important point requires to be determined : — viz., how much brake force is actually required for each vehicle? For convenience let us suppose, as is nearly the case, that each carriage weighs 9 tons or 20,000 lbs. Then, according to requirement No. 2, a total brake-block pressure of at least 35,000 lbs. will be required ; and it would be preferable to have a still higher pressure. In practice the brake-blocks when out of action must be kept a certain distance away from the wheels, in order to prevent any liability to drag against them ; and this distance, after being once adjusted, gradually increases by the wear of the blocks, and often exceeds three-quarters of an inch ; while the springing of the brake gear under great strain also adds to the extent of movement required in the brake force before the blocks are fully applied. Thus it may be safely assumed that it requires not less than a pressure of 35,000 lbs. and a travel of one inch to apply the brakes upon each nine-ton vehicle ; or if the pressure were 3,500 lbs., acting at a leverage of 10 to 1, there must be a travel of ten inches in order to produce the same result.

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Now, if this work has to be done with a piston working in a cylinder, or its equivalent, the cylinder must be of such a size that the area of the piston in square inches, multiplied by the stroke of the piston and by the pressure in lbs. per square inch, shall exceed 35,000. Thus in the above case, supposing the pressure to be 100 lbs. per sq. inch., a piston of 10 in. stroke, and of 35 sq. in. area, is the smallest that would be allowable. Any brake-cylinder having a less capacity than this will make it necessary that the blocks be kept closer to the wheels, or else that the brake-block pressure be reduced.

It is obvious that each system of brakes could be made to operate upon the same kind of brake levers and blocks; and therefore, in comparing the various systems of brakes, they ought to be applied to like vehicles, and to be made of such dimensions as to give the same total brake power.

The author had originally intended to continue these experiments on brakes, so as to ascertain the retarding power of the different kinds of continuous brakes now in use, on trains under similar conditions, of equal weight, and running at the same speed. He had the opportunity, through the courtesy of the North Eastern Railway Company, of making a few comparative experiments upon the Westinghouse Automatic Air Brake, and the Vacuum Brake. These experiments, although highly interesting as far as they went, left many points unsolved. But they went sufficiently far to show that, in the present stage of the brake question, a series of experiments which touch upon the interests of rival inventors, who have invested large sums of money in their respective enterprises, cannot be effectually carried on by a private individual. It does not seem probable that the different railway companies will arrive at an understanding to initiate and carry on joint experiments for ascertaining the performances of the various kinds of continuous brakes. The only way, therefore, by which an independent enquiry could be made would be by a Government Commission, appointed on the principle of the Commission which enquired into the application of iron to railway structures in 1849, viz., to state facts and lay down principles.

THE PARIS AND LYONS RAILWAY TESTS.

The following paper was read before the Institution of Mechanical Engineers at same meeting when Capt. Galton read his third paper on the effect of brakes upon railway trains (April 24, 1879), and relates to some tests made by the Paris & Lyons Railway in April, 1879, and reported by the chief engineer of that road, M. Marié.

ON RECENT BRAKE EXPERIMENTS UPON THE LYONS RAILWAY.

By M. GEORGE MARIÉ, of Paris.

I. Particulars of Apparatus.

The Paris and Lyons Railway has lately experimented on two trains, one fitted with the Westinghouse brake, and one with the Smith Vacuum brake. Both trains were alike, and were composed as follows: —

Vehicle.	Axles.	Load per Axle. Lbs.	Total Load. Lbs.
1 engine, 4 axles (in working order)	2 driving axles, together 2 loose axles, together	55,125 44,100	99,225
1 tender, 3 axles (in working order)	1st axle, with brake . 2d axle, without brake . 3d axle, with brake .	25,357 17,640 25,357	68,354
25 carriages (empty), 3 axles .	1st axle, with brake . 2d axle, without brake . 3d axle, with brake .	7,276 6,394 7,276	20,946
Same carriages (loaded), 3 axles	1st axle, with brake . 2d axle, without brake . 3d axle, with brake .	8,676 7,594 8,676	24,946

The engine is not fitted with any brake, except the "Le Chatelier" counterpressure apparatus. This apparatus,* as improved by the chief

* See Proceedings 1870, p. 21.

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engineer, M. Marié, has worked excellently for fifteen years, in daily use, both in all stops at stations, and also on long inclines. Some remarks will be made hereafter on the power of the counterpressure apparatus compared with a brake on the driving wheels.

Each carriage had only two axles fitted with brakes, the middle axle being left free; the fear of the complication arising from a six-wheel brake was the reason of this; but, in order to have power enough, a great brake-block pressure was provided. The following table shows the brake-block pressure on every axle of the train. The pressure in the brake cylinder is here supposed to be 37 lbs. per square inch; and the vacuum in the "Hardy" sack to be 16 inches of mercury. These pressures must be considered as an average of the ordinary pressures in practice.

	Air Pressure, or Vacuum.	Pressure on the Outside Blocks.	Pressure on the Inside Blocks.	Total Brake-block Pressure per Axle.	Load on Rail for each Braked Axle.	Ratio of Brake-block Pressure to Load.
WESTINGHOUSE.	Lbs. per Sq. in.	Lbs.	Lbs.	Lbs.	Lbs.	Per Cent.
Tender (1st and 3rd axle)	37	6,666	10,016	16,682	25,357	66
Empty carriage (1st and 3rd axle braked) . .	37	4,191	6,303	10,494	7,276	144
	37	4,191	6,303	10,494	8,676	121
VACUUM.	Inches Vacuum.	Lbs.	Lbs.	Lbs.	Lbs.	Per Cent.
Tender (1st and 3rd axle)	16	15,020	9,874	24,894	25,357	98
Empty carriage (1st and 3rd axle braked) . .	16	8,342	5,045	13,387	7,276	184
	16	8,342	5,045	13,387	8,676	154

The pressures were not large enough to skid the wheels at high speeds, but at low speeds the wheels were skidded, especially with empty carriages. This latter is no real disadvantage, because in ordinary stops the driver can moderate the brake power. Mr. Westinghouse, however, in order to avoid skidding under any circumstances, fitted, as a trial, twelve carriages with reducing valves, operated by the friction of the brake-blocks. The arrangement of these was the same as is given in Captain Galton's paper (Figs. 35 to 37, pages 83 and 85).

It will be seen that, in the case of the Westinghouse brake, the pressure on the outside blocks (or those furthest from the centre of the vehicle)

is less than on the inside blocks, which arrangement has the disadvantage of creating a strain on the horn plates equal to the difference of these two pressures; but has, on the other hand, the following advantage. When the brake is applied to the whole train, each carriage is subject to a strain, created by inertia, equal to the mass of the carriage, multiplied by the rate of retardation of the train. This strain equals, on an average, about $\frac{1}{10}$ of the weight of the carriage; it acts as a forward push applied to the centre of gravity of the carriage, and changes the distribution of the weight on the axles, the front axle becoming more loaded than usual, and the rear axle less. This is an important matter, because the springs of the carriages are sometimes damaged by the action of this extra load on the front axle. Mr. Westinghouse has therefore arranged his brake gear in such a way as to create a vertical force, counteracting partially this extra load, by giving more pressure on the inside blocks than on the outside ones. These pressures being different, the frictional resistances are different also, and the difference forms a vertical force acting upwards on the springs of the front axle, thereby balancing so far the action of inertia.

In the case of the Vacuum brake gear the pressure on the outside blocks is greater than on the inside ones, which causes a reverse action, so as to add to the extra load created by inertia upon the front axle. From this it follows that the compression of the front springs is somewhat greater in the case of the Vacuum than of the Westinghouse brake. In the Westinghouse brake gear this difference of pressures is equal to $6303 - 4191 = 2112$ lbs. for each axle; and the difference of frictional resistances is equal to $\frac{2112}{5} = 422$ lbs. (with a coefficient of friction of .20). In the Vacuum brake gear the difference of pressures is equal to $8342 - 5045 = 3297$ lbs.; the difference of resistances is therefore equal to $\frac{3297}{5} = 659$ lbs. Thus with the Westinghouse brake there is a counteracting force, as described, of 420 lbs.; whilst with the Vacuum brake there is an augmenting force of 660 lbs. From this cause the front springs are more loaded with the Vacuum brake than with the Westinghouse; and this strain is still greater towards the

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end of the stop, because the friction increases considerably at that moment, as may be seen in the friction diagrams of the Brighton experiments. The practical result of this during the trials was that in the Westinghouse train only one front spring was flattened down, while in the Vacuum train all were. The author does not understand the object of the latter type of brake gear, which is generally applied with the Smith brake, and is also extensively used by the Great Northern Railway in England.

It is impossible to avoid entirely the above-mentioned strain on the horn plates; and in addition, the horizontal force retarding the train must produce another strain on the horn plates, which is equal to $\frac{10,494}{5} = 2,099$ lbs. per axle for the Westinghouse brake. Thus with this brake the horn plates of the front axle have to support two strains in opposite directions, one equal to the difference of the brake-block pressures, or 2,112 lbs., and one equal to the retarding force, or 2,099 lbs.; the resultant strain is therefore only $2,112 - 2,099 = 13$ lbs. But on the horn plates of the rear axle the forces act in the same direction, and therefore the total strain is equal to $2,112 + 2,099 = 4,211$ lbs. From this point of view it would be better to have the same brake-block pressures on both sides of the wheel, so that the strain on the horn plates should be only 2,099 lbs. at each end of the carriage; the advantage of unequal pressures, as above described, would then be lost, but still the author would prefer this arrangement.

The stroke of the piston, both in the air cylinders and in the Hardy sacks, was calculated so as to have a theoretical clearance of $\frac{3}{4}$ inch between the blocks and the wheels, when the brakes were off. In the trials, the distance between each block and its wheel was $\frac{3}{8}$ inch when the brakes were off; the difference, $\frac{3}{8}$ inch, was allowed for the bending and springing of the brake gear.

II. Practical Working of the two Brakes.

Trains fitted with a Westinghouse and with a Vacuum brake have been running for two months from Paris to Montereau (49 miles) and

PARIS AND LYONS RAILWAY TESTS

back, and from Paris to Corbeil (20 miles) and back. The Westinghouse brake has worked very well when there has been no leakage in the pipes, but it is necessary to watch all the apparatus with the greatest attention ; sometimes one or two of the triple valves get out of order, and disturb the action of the brake, causing very severe shocks to the couplings, especially with trains of twenty-four carriages. The Vacuum train has also given good results, but the couplings are often damaged ; the operation of putting the couplings together is much more difficult than with the Westinghouse brake. With both brakes the passengers generally feel no shock, provided the driver releases the brake a few yards before the end of the stop. The practical trial of both these trains has as yet been too short for giving any definite conclusion.

III. Experiments of the 1st and 2nd April.

The London, Brighton and South Coast Railway, as represented by their general manager, Mr. Knight, and locomotive superintendent, Mr. Stroudley, sent over to the Lyons Railway the experimental van already used during Captain Douglas Galton's experiments at Brighton and York. The author takes this opportunity of thanking those gentlemen, and also Captain Galton, Mr. Westinghouse, and Mr. Kapteyn, of Paris, for their assistance in these experiments. A description of the apparatus has already been given in Captain Galton's papers on the subject. In the present experiments two diagrams only were taken for each stop ; first, the diagram from the speed indicator, giving the square of the speed of the train at each point of the distance run ; second, the diagram giving the brake-block pressure on the front axle of the van. This axle had been fitted with a Westinghouse brake and with a Vacuum brake, which could be used independently. In Captain Galton's experiments the abscissæ were made proportional to the time, the recording cylinders being connected with a water clock, and so turned round with a uniform speed. In the Lyons experiments, the abscissæ were made proportional to the distance run by the train ; for this purpose the recording cylinders were

PARIS AND LYONS RAILWAY TESTS

connected with the rear axle of the van ; that axle had no brake, and therefore gave a distance exactly proportional to the distance run by the train. When the train was run without brakes being applied, this connection between the recording cylinders and the rear axle was broken ; when the driver applied the brake, the connection was immediately and automatically established by means of friction gearing, actuated by electricity. The brake-block pressure is exactly proportional to the air pressure in the brake cylinder, or to the vacuum in the Hardy sack. On the diagram, Fig. 45, are two scales, adapted for measuring the air pressure and the vacuum from the diagram of the brake-block pressures. The lines marked W denote the Westinghouse brake, and the lines marked V the Vacuum. The full lines show the speeds, and the dotted lines give the air pressure in the brake cylinder in lbs. per square inch, or the vacuum in the Hardy sack in inches of mercury. It will be seen that in Captain Galton's diagrams the lines of speed are convex towards the base line, while in these they are concave ; the reason of this is the difference already explained between the abscissæ used in each case.

On 1st April experiments were made with the Vacuum brake. From Paris to Montargis (73 miles) the train was composed of engine, tender, ordinary van, experimental van, twenty-two carriages. From Montargis to Paris the train was much shorter, comprising engine, tender, ordinary van, experimental van, six carriages. On 2nd April the same experiments were made with the Westinghouse brake, and with the same number of vehicles. A great many diagrams were taken, from which five are chosen, representing the average of all the cases. By the aid of those five diagrams, Figs. 45 to 49, the results may now be described.

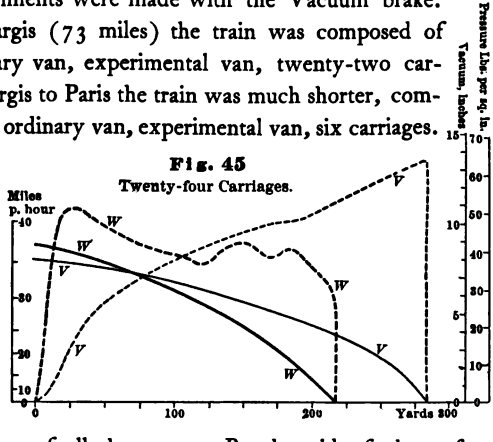

Fig. 45
Twenty-four Carriages.

PARIS AND LYONS RAILWAY TESTS

Fig. 45 represents two stops with twenty-four carriages (including the two vans), one stop with the Westinghouse, the other with the Vacuum brake. The weights of the trains were as follows : —

	Weight on Unbraked Wheels. Lbs.	Weight on Braked Wheels. Lbs.
Engine	99,225	
Tender	17,640	50,714
Carriages and van, empty	147,062	334,696
Experimental van, loaded	10,000	10,400
Total	273,927	395,810

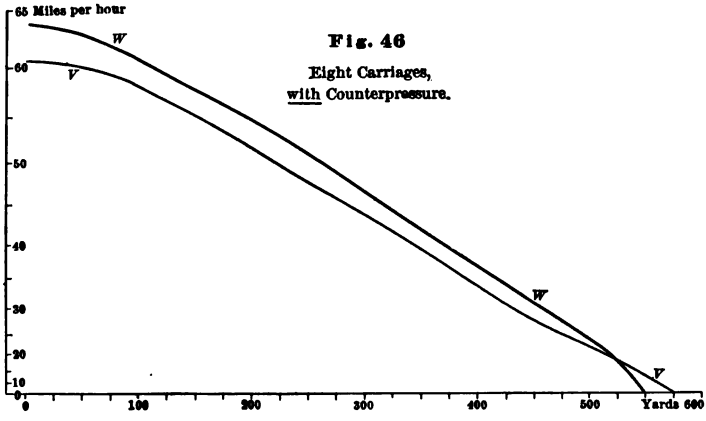

Fig. 46

Eight Carriages, with Counterpressure.

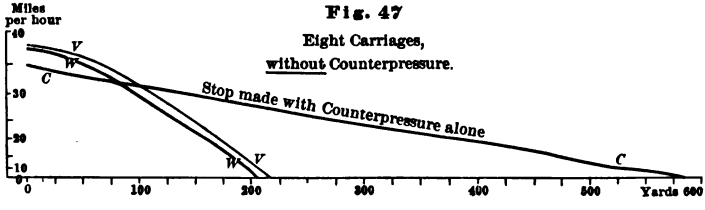

Fig. 47

Eight Carriages, without Counterpressure.

Air Brake Tests

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Total weight of the train, 669,737 lbs.; proportion on braked wheels, 59 per cent.

In order to be exact there ought to be added to the total weight of the train the weight of all the unbraked wheels, because the brake is obliged to destroy the rotating momentum of those wheels. But, as this error is very small, and the same for both brakes, it has not been taken into consideration in the calculations. The results of Fig. 45 are therefore as follows: —

Brake.	Speed of Train. Miles per Hour.	Length of Stop. Yards.	Duration of Stop. Seconds.	Gradient.	State of Rail.
Westinghouse .	37	217	20½	{ Rising 1 in 200 }	Dry.
Vacuum . . .	35	280	24½	Level	Rather Wet.

The diagram shows the variation of the air pressure in the brake cylinder, and of the vacuum in the Hardy sack. The full pressure was almost instantaneously applied with the Westinghouse brake; its variation shows the action of the regulating valve in the van. The vacuum increases slowly, and reaches 13½ inches at the end of the stop; in the rear of the train the vacuum was no doubt created more slowly still, but no experiments with recording apparatus were made to ascertain this point.

This trial was the most unfavorable for the Vacuum brake, the number of carriages being large and the speed small.

Figs. 46 and 47 show a few stops with the return train of eight carriages (including the two vans).

The weights of the train were as follows:

	Weight on Unbraked Wheels. Lbs.	Weight on Braked Wheels. Lbs.
Engine	99,225	
Tender	17,640	50,714
Seven carriages, empty	44,758	101,864
Experimental van, loaded	10,000	10,400
Total	171,623	162,978

PARIS AND LYONS RAILWAY TESTS

Total weight of the train, 334,601 lbs. ; proportion on braked wheels, 49 per cent.

The particulars of the stops were as follows :

Brake.	Speed. Miles per Hour.	Length of Stop. Yards.	Duration of Stop. Seconds.	Gradient.	State of Rail.
Westinghouse, Fig. 46 .	63½	550	32	Falling 1 in 200	Dry.
Vacuum, Fig. 46 . .	60½	570	37	do.	Quite wet.
Westinghouse, Fig. 47 .	37	203	16½	Falling 1 in 1000	Dry.
Vacuum, Fig. 47 . .	37	213	19½	do.	Quite wet.

The two first stops (Fig. 46) were made with the aid of the counterpressure of the engine ; the two last (Fig. 47) were made without counterpressure. The line C of Fig. 47 shows a stop made with counterpressure alone.

As may be seen, the results are not very different, the trains having very few carriages.

Fig. 48

Westinghouse Brake worked from Rear Van.

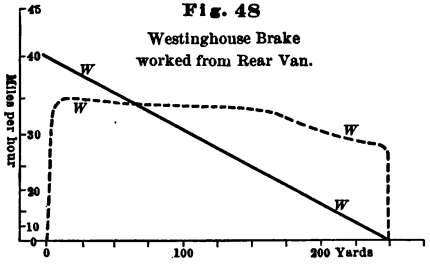
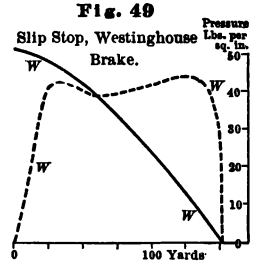


Fig. 49

Slip Stop, Westinghouse Brake.



References { W = Westinghouse Brake V = Vacuum Brake
——— Speed - - - - - - - Pressure or Vacuum

Fig. 48 shows a stop obtained with the Westinghouse brake, worked from the rear van of the train. The following are the particulars :

Speed, 40 miles per hour.
Length of stop, 248 yards.
Time, not observed.
Gradient, level.
Rail, dry.

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The train had exactly the same composition as that in the experiments with eight vehicles; the regulator of the engine was kept full open until the train had come to rest.

Fig. 49 shows a slip experiment with the Westinghouse brake. The part of the train which was slipped was composed of the experimental van and six carriages. The weights were as follows:

	Weight on Unbraked Wheels. Lbs.	Weight on Braked Wheels. Lbs.
Experimental van, loaded . . .	10,000	10,400
Six carriages, empty	38,364	87,312
Total	48,364	97,712

Total weight of the train, 146,076 lbs.; proportion on braked wheels, 67 per cent.

The following are the particulars of the stop, which was a very good one:

Speed, 41 miles per hour.

Length of stop, 150 yards.

Duration of stop, 12½ seconds.

Gradient, level.

Rail, dry.

In this stop, as in the last, the recording instruments were started by the air pressure in the brake cylinder of the van, instead of being started by electricity as before. There was in consequence a slight loss of time, especially in the stop from the rear van, Fig. 48.

IV. Comparison of the Retarding Forces in Different Stops.

It is easy to compare stops with each other, although the speed, the gradient, and the proportion of weight on braked wheels be different in each. This can be done by calculating the retarding forces of the brake for each stop.

If we called S the speed in miles per hour, *l* the length of the stop

in yards, and W the weight of the train, then the retarding force F is given by the formula :

$$\frac{F}{W} = 0.011 \times \frac{S^2}{l}.*$$

The diagrams give with precision the values of S and l in each stop; hence it is easy to calculate the retarding force in each case. On the diagrams, the ordinates are proportional to the square of the speed, and the abscissæ proportional to the length of stop; thus, the average retarding force is proportional to the inclination of the straight line drawn between the extremities of the speed curve, while the exact retarding force at each point of the diagram is given by the inclination of the tangent to the curve at that point. We can now compare stops made at different speeds.

To compare stops made on different gradients, we must add the gradient to $\frac{F}{W}$, with the sign + if it is falling, and with the sign — if it is rising. We will call $\frac{F'}{W}$ this corrected retarding force.

To compare stops in which the percentage of weight on braked wheels is different, let A be that percentage. If we multiply $\frac{F'}{W}$ by $\frac{100}{A}$, we have a number $\frac{F''}{W}$, which would be the retarding force for a train stopped on a level line with the whole weight of the train braked.

If we calculate the values of $\frac{F''}{W}$ for all the stops, the numbers obtained compare exactly the powers of the brakes, whatever may be

---

* Let s be the speed of the train in yards per second, t the number of seconds of the stop, and l the length of the stop in yards. Then, if we suppose the retardation k to be constant during the stop, $s = kt$. Also $l = \frac{1}{2}kt2$; hence $l = \frac{1}{2}k\frac{s^2}{k^2} = \frac{1}{2}\frac{s^2}{k}$; thus, if we take the value of k from this formula, we have $k = \frac{s^2}{2l}$.

Now let g be the acceleration of gravity in yards per second; let F be the retarding force of the brake in the whole train, and let W be the total weight of the train. Then, because forces are proportional to their accelerations, we have :

$$\frac{F}{W} = \frac{k}{g} = \frac{s^2}{2lg} = 0.011 \times \frac{S^2}{l}.$$

PARIS AND LYONS RAILWAY TESTS

the circumstances of the stop. The following Table gives this comparison for the present diagrams:—

	Speed S.	Length l.	$\frac{F}{W}$	Gradient.	$\frac{F'}{W}$	Percentage of Weight on Braked Wheels.	$\frac{F''}{W}$ Power of the Brake.
Westinghouse, alone: 24 carriages, Fig. 1 . .	37	217	0.075	Rising 1 in 200	0.070	59	0.119
Vacuum, alone: 24 carriages, Fig. 1 . .	35	280	0.057	Level	0.057	59	0.096
Westinghouse, alone: Slip experiment, Fig 5 .	41	150	0.130	do.	0.130	67	0.200
Westinghouse, alone: Brake from rear van, Fig. 4	40	248	0.080	do.	0.080	49	0.160
Westinghouse, alone: 8 carriages, Fig. 3 . .	37	203	0.085	Falling 1 in 1000	0.086	49	0.170
Vacuum, alone: 8 carriages, Fig. 3	37	213	0.080	do.	0.081	49	0.160
Counterpressure, alone: 8 carriages, Fig. 3 . .	35	583	0.024	Level.	0.024	16	0.150

The stops in Fig. 46 have not been worked out because they were made with the brake and the counterpressure together.

The retarding force $\frac{F}{W}$ ought to be diminished by the ordinary resistances of the train, that is to say, by 0.003 to 0.008. This makes but a small difference when the proportion of braked weight is large; but in the last stop, with counterpressure alone, this correction gives to $\frac{F''}{W}$ a value 0.125 instead of 0.150.

V. General Conclusions.

We have seen that the value of $\frac{F''}{W}$ is the best comparison for the power of the brakes in all cases. Now with the Westinghouse brake $\frac{F''}{W}$ is generally between 0.120 and 0.200, while with the Vacuum brake $\frac{F''}{W}$ is generally between 0.100 and 0.160. This shows a slight advantage for the Westinghouse brake, but it must be remarked that the rail was better during the trial of the Westinghouse than of the Vacuum

PARIS AND LYONS RAILWAY TESTS

brake. We have also seen that the value of $\frac{F''}{W}$ for the counterpressure is 0.125, while the average of the Westinghouse trials gives 0.160, with a brake-block pressure of about 140 per cent. of the weight on the braked wheels. Thus the counterpressure on the driving wheels is as powerful as a Westinghouse brake which has a pressure of $140 \times \frac{125}{160} = 109$ per cent. of the weight on those wheels. It may be suggested that in a quick stop the time occupied in reversing the steam on the engine must practically diminish the power of the counterpressure; this is true, but on the other hand the brake-block pressure on the driving wheels with the Westinghouse brake is generally less than 109 per cent., and often less than 80 per cent. Thus the counterpressure is as powerful as the Westinghouse brakes generally in use on the driving wheels. On the Lyons Railway the drivers have been accustomed to the counterpressure for fifteen years; hence, whatever may be the final choice of brake, the Company will put no brake on the driving wheels.

The diagrams show that the Westinghouse brake comes on almost instantly over the whole train; it is not the same with the Vacuum brake. There the brake goes on first upon the front carriages, and the buffers are consequently compressed; afterwards the carriages all become braked, and the buffers return to their first position, but not without oscillations which are serious, both for the passengers and for the couplings themselves. In the Westinghouse brake this action is much slighter.

In all the trials the wheels skidded only at a very low speed; hence the regulating valves did not show any great advantage in the length of the stop. They save the tires by preventing the wheels from skidding, and they save also the springs of the carriages by diminishing the shock felt at the last moment of a stop. Though a very ingenious improvement, yet, if the driver can really graduate the strength of the brake, it may be doubtful whether they are necessary in continuous brakes; thus one more complication may, perhaps, be avoided.

The Lyons Railway had never previously had an accident caused by the breaking of draw-bars in a passenger train, but several were broken

PARIS AND LYONS RAILWAY TESTS

in the trains fitted with the Westinghouse and Vacuum brakes. Thus, if there has been no such breaking of draw-bars in past times, yet these are almost sure to occur frequently with the use of continuous brakes: and as there are on the railway several very steep gradients, it would seem that a non-automatic brake would on this line at least be dangerous, unless, to avoid accidents, the ordinary hand brakes are still kept in use on the trains.

The arrangements of the Westinghouse brake are certainly rather complicated, especially the air pump and the triple valves. As regards the pump, the author thinks that it would be difficult to make an air pump more simple and at the same time able to satisfy all conditions. And as regards the triple valve, he thinks it is impossible to simplify it without losing one of the two following advantages — the quickness of application of the brake, or its graduation in the stops. It might, however, be rendered less delicate by making it larger and stronger. All the other parts of the brake are quite satisfactory.

All the parts of the Vacuum brake are very simple and strong, but the leather of the Hardy sack seems to be a bad material for practical work. Some arrangement of metallic pistons and cylinders would seem preferable, but practice alone can decide this question. The arrangement of the brake gear is not quite satisfactory, but it would be easy to improve it.

The above opinions must be taken as those of the author alone, and as requiring to be checked by longer experience. Both brakes will be tried on long inclines, and a uniform speed maintained with them if possible. Until these trials have taken place, no decisive opinion can be given by the railway company.

THE BURLINGTON BRAKE TRIALS.

These trials were carried on at the instance of the Master Car Builders' Association, whose Committee on Automatic Freight Car Brakes were directly in charge.

Two series were run, the first in 1886 and the second during the year following. In the latter year this Committee made a report to the meeting of the M. C. B. Association, at St. Paul, Minn., on June 15th, 16th, and 17th, which contained a full detailed description of the tests, and the following pages are taken from it:

Programme of General Tests, 1886.

1. Fifty-car trains on down grade 53 feet per mile, running forward, quick stops.

a. All cars loaded, 30 and 20 miles per hour.

b. All cars empty, 40 and 20 miles per hour.

c. Cars mixed (see below), 40 and 20 miles per hour.

NOTE.—Half the cars to be loaded and half empty, 75 per cent. of the latter to be on front half of train. During these tests, the rapidity with which the train gets away after a stop will be noted, the time being taken from stop to start.

2. Fifty-car trains on level, running forward, quick stops.

Same as tests on grade, except that trials are on level.

NOTE.—In order to attain a speed of 40 miles per hour, pushers or double-headers will be used, at option of brake company.

3. A train of fifty (50) half loaded and half empty cars, 75 per cent. of the latter to be on front half of train, to be let down a grade of 53 ft. per mile 3 miles long. Speed of 20 miles per hour at top of grade to be reduced to 15 miles per hour and maintained without material variation all down the grade.

4. Twenty-five (25) car trains. Twelve (12) cars to be loaded, and thirteen (13) empty, about 75 per cent. of empties being on the front half of train. Tests to be made on a down grade of 53 ft. per mile, running forward at speeds of 40 and 20 miles per hour.

5. Similar trains to above. Tests to be made on level at 40 and 20 miles per hour.

Air Brake Tests

THE BURLINGTON BRAKE TRIALS

6. Similar trains to above. Tests to be made ascending grade of 53 ft. per mile, engine in front of train pulling. Speed, about 12 miles per hour.

7. Engine tests. Engine and dynamometer car. Two stops on level track at 20 and 40 miles per hour, and two stops on 53 ft. grade at 20 and 40 miles per hour.

8. Hand-brake stops with engine and tender power brakes; 25 mixed car train. Two stops on level track at 20 and 40 miles per hour, and two stops on 53-ft. grade at 20 and 40 miles per hour.

9. Train resistance test; 25 mixed car train.

(1.) To pass No. 1 stop-post at 20 miles per hour, letting the train drift till it stops, no brakes being applied.

(2.) To pass No. 3 stop-post at 5 miles per hour, letting the train drift until No. 4 post is reached, at which point the accelerated speed shall be recorded and the train stopped.

10. Empty 50-car train; the 30 forward cars to have automatic brakes, and the rear 20 cars to be without automatic brakes. Three stops each at 20 and 40 miles per hour on the levels and 20 and 40 miles per hour on the 53-foot grade.

Special Tests.

1. Twenty-five-car trains. Half the cars to be loaded and half empty, 75 per cent. of the empty cars being on the front half of the train. Tests on the level. Trains to be broken in two near the center. Speeds 40 and 20 miles per hour. After the train is broken in two, any assistance necessary will be rendered only by a brakeman, who shall be riding at the rear of the train when the breakaway occurs.

NOTE.—In all the above tests, all the cars in a train are fitted with the same automatic brake.

2. Similar trains as above as regards number and loads of cars. One-half of the cars to be equipped with the same automatic brake, and the other half with hand brakes only. Three cars with hand brakes only next tender, then three with train brake, and so on. Tests on the level. Speeds, 30 and 20 miles per hour.

THE BURLINGTON BRAKE TRIALS

3. Twenty-five (25) car mixed trains with the same train brake on twelve (12) cars next tender. The rear 13 cars to have hand brakes only. Speeds, 40 and 20 miles per hour. Tests to be on level.

4. Fifty-car trains. Trains to be composed in equal proportions of different train brakes that will operate together. Half of the cars empty and half loaded — about 75 per cent. of the empty cars in front of train.

5. Consolidation engine train test; 50 loaded car train. Two stops each to be made at stop-posts Nos. 1, 2, 3 and 4 at 20, 30, 20 and 30 miles per hour respectively.

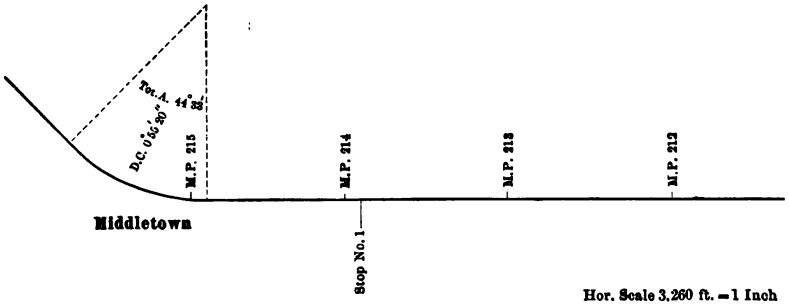
[NOTE.—General tests 4 and 6 were erased at a joint meeting held at Burlington prior to the tests, and Nos. 7, 8, 9 and 10 and Special test No. 5 were added. Special tests Nos. 2, 4 and 5 were inserted in the interests of the buffer brakes.]

A dynamometer car to be placed in the front end of each train, with complete recording mechanism. In the middle box car of each train a portable apparatus to be placed for recording diagrams; showing, 1st, a strain line in pounds exerted on the brake lever during the stops, and, 2d, a speed line in miles per hour during each stop. An electric signal to be arranged for communication between the front and rear ends of the train.

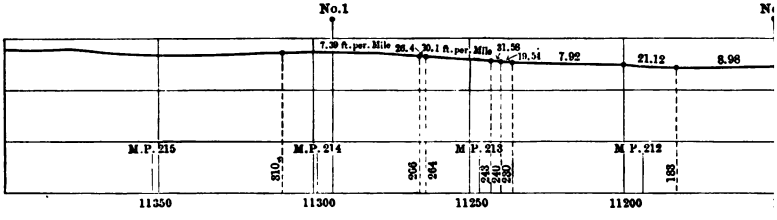
The ground selected for the trials was a stretch of track commencing eight miles west of Burlington, the Chicago, Burlington & Quincy shops being located midway in the course. The first 5 miles, it will be seen by reference to plate I, is a level stretch of single track, on which is located stops Nos. 1 and 2, a distance of 2.858 miles being between the stops. The last 3 miles of the course is double-tracked, something over 2 miles of it being on a down grade of 53 ft. to the mile. On this we find stops 3 and 4,— No. 3 being 2.21 miles from No. 2, and No. 4, 1.242 miles from No. 3. The natural advantages of such a course soon became apparent. Without in any way interfering with the regular traffic of the road, the Committee were enabled under favorable circumstances to make five trips a day, equal to an 80-miles' run, and to dispose of 20 of the stops.

Profile and Plan of track where

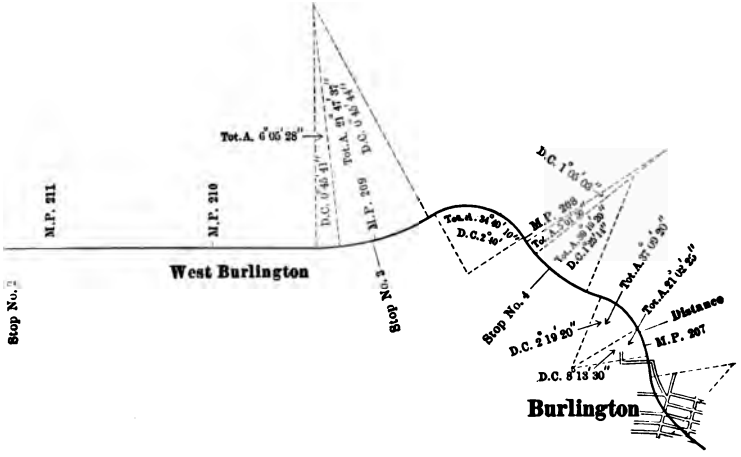
Plate I

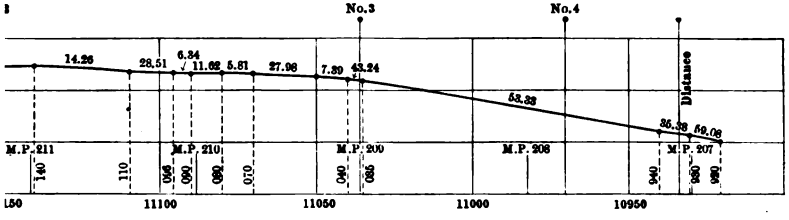


Hor. Scale 3,260 ft. = 1 Inch
Vert. " 195 " "



the Burlington Trials were Held.





Air Brake Tests

THE BURLINGTON BRAKE TRIALS

The companies that entered the 1886 contest were :

1. The Westinghouse Automatic Brake Company of Pittsburg. Its equipment was attached to 50 Chicago, Burlington & Quincy standard 40,000-lbs. box cars.

2. The Eames Vacuum Brake Company of Boston, Mass. Its appliances were applied to 50 40,000-lbs. cars of the Indianapolis, Decatur & Springfield Railroad.

3. The American Brake Company of St. Louis, Mo., with 50 standard 40,000-lbs. cars of the St. Louis & San Francisco Railroad.

4. The Widdifield & Button Brake Company of Uxbridge, Ont., Canada, with 50 cars of 40,000 lbs. capacity of the Lehigh Valley Railroad.

5. The Rote Brake Company of Mansfield, O., with 50 standard 40,000-lbs. cars of the Chicago, Rock Island & Pacific Railroad.

These five competitors may be classed as representing two types of brakes : the Continuous or Air brakes being represented by the Westinghouse and the Eames, and the Independent or Buffer brakes by the American, the Widdifield & Button, and the Rote. The general features of the brakes may be obtained fiom Figs. 58, 59, and 60. The cars were all of the eight-wheel type.

The Westinghouse Brake.

The Westinghouse automatic freight-car brake, as used in the contest of 1886, is illustrated as follows :

Fig. 50 shows the triple valve, reservoir, and brake-cylinder. The triple valve is shown in section in Fig. 51, and thus described :

The piston, 5, works in the chamber *B*, and carries with it a slide valve, 6. Air enters from the main pipe through the four-way cock into the drain-cup *A*, and passes to the chamber *B*, forcing the piston horizontally, and uncovering the small feed-groove in the side of the chamber, which permits air to flow past the piston into the auxiliary reservoir, while, at the same time, there is an open communication from the brake-cylinder to the atmosphere, through the passages *d*, *e*, *f*, and *g*.

WESTINGHOUSE TRIPLE VALVE, RESERVOIR AND BRAKE CYLINDER.

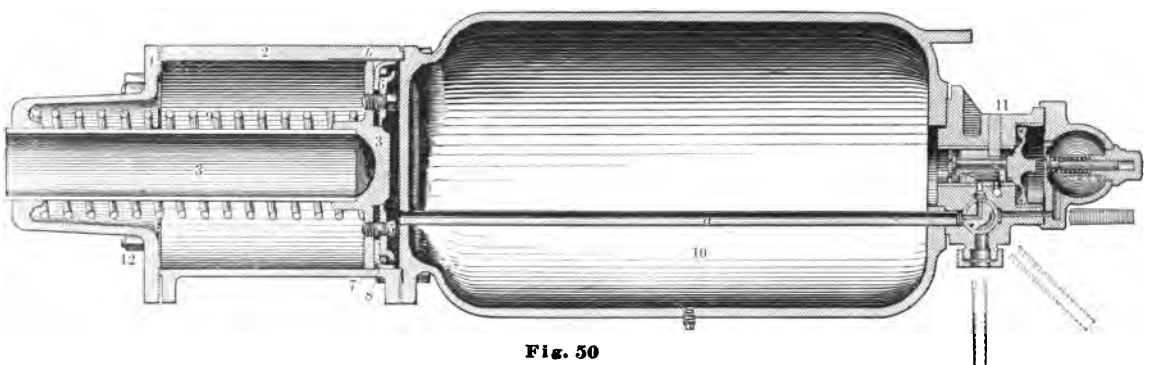


Fig. 50

Air Brake Tests

THE BURLINGTON BRAKE TRIALS

To apply the brakes with their full force, the compressed air in the main brake-pipe is allowed to escape, when the greater pressure in the auxiliary reservoir moves the piston 5 beyond the feed-groove, thus preventing the return of air from the reservoir to the brake-pipe. As the piston travels, it moves with it the slide valve 6, so as to permit air to flow directly from the auxiliary reservoir into the brake-cylinder, which forces the pistons out and applies the brakes. The brakes are released by again admitting pressure into the main brake-pipe from the main reservoir, which pressure, being greater than that in the auxiliary reservoir, forces the piston 5 back to the position shown in the drawing, recharges the reservoir, and at the same time permits the air in the brake-cylinders to escape. To apply the brakes gently, a slight reduction is made in the pressure in the main brake-pipe, which moves the piston slowly until it is stopped by the graduating spring 9; at this point the opening *l* in the slide valve is opposite the port *f*, and allows air from the auxiliary reservoir to feed through a hole in the side of the slide valve and through the opening *l* into the brake-cylinder. The passage *l* is opened and closed by a small valve, 7, which is attached to and moves with the piston 5, provision being made for a limited motion of these parts without moving the valve 6. When the pressure in the auxiliary reservoir has been reduced, by expansion into the brake-cylinder, until it is the same as the pressure in the main brake-pipe, the graduating spring pushes the piston up until the small valve, 7, closes the feed opening, *l*. This causes whatever pressure is in the brake-cylinder to be retained, applying the brakes with a force proportionate to the reduction of pressure in the brake-pipe.

To prevent the application of the brakes from a slight reduction of pressure, caused by leakage in the brake-pipe, an oval groove is cut in the body of the car-cylinder, $\frac{9}{64}$ in. in width and $\frac{6}{64}$ in. in depth, and of such a length that the piston must travel 3 inches before the groove is covered by the packing-leather. A small quantity of air, such as results from a leak, passing from the triple valve into the car-cylinder, has the effect of moving the piston slightly forward, but not sufficiently to close the groove, which permits the air to flow out past

the piston. If, however, the brakes are applied in the usual manner, the piston will be moved forward, notwithstanding the slight leak, and will cover the groove.

When the handle of the four-way cock is turned down, there is a

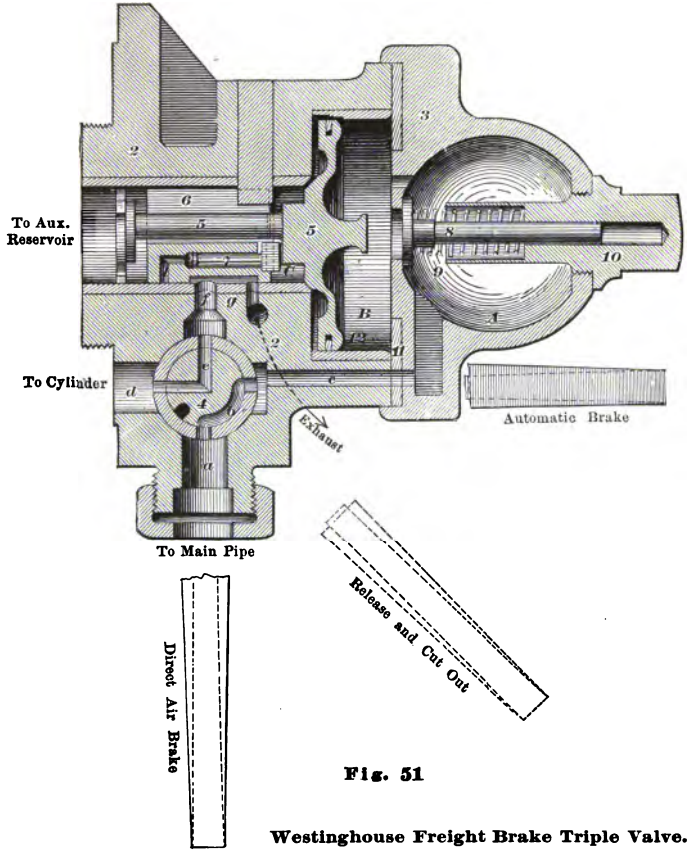


Fig. 51

Westinghouse Freight Brake Triple Valve.

direct communication from the main brake-pipe to the brake-cylinder, the triple valve and auxiliary reservoir being cut out, and the apparatus

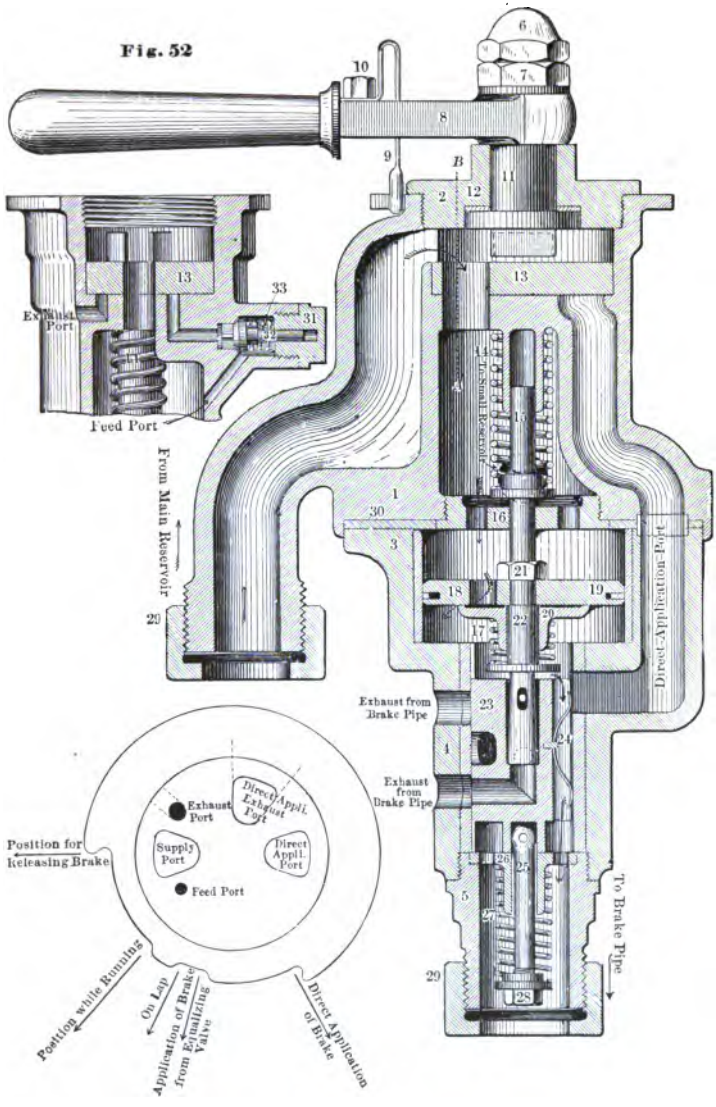
can then be worked as a non-automatic brake by admitting the air into the main brake-pipe and brake-cylinder to apply the brakes. When, from any cause, it is desirable to have the brake inoperative on any particular car, the four-way cock is turned to an intermediate position, which shuts off the brake-cylinder and reservoir, leaving the main brake-pipe unobstructed to supply air to the remaining cars.

This position of the handle also releases the brakes on a car when it is detached from the locomotive. The engineer's valve used in the 1886 and 1887 tests is shown by Fig. 52.

The cut shows the valve in the position for releasing the brakes; the pressure from the main reservoir passing through the rotary valve 13 and to the main brake-pipe, as shown by the arrows. While running, the handle of the valve is turned to the position shown in the diagram, when the air enters through the feed port, passing the feed valve 32, which is held to its seat by the spring 33, which causes an excess of pressure in the main reservoir over that in the brake-pipe equal to the strength of the spring 33, and insures a quick release of the brakes.

The chamber A is connected to a small reservoir, not shown in the cut, which simply serves to increase the effective capacity of the chamber. To apply the brakes, the handle is turned to the position for application shown in the diagram, and a portion of the air in the chamber allowed to escape from the supply port, causing a corresponding reduction of pressure in the chamber, after which the handle is turned to put the valve on lap. The excess of pressure in the main brake-pipe over that in the chamber A forces the piston 18 up, unseating the valve 22 and allowing air to escape through the exhaust from brake-pipe, until the pressure in the brake-pipe is equal to that in the chamber, the valve 22 remaining open until the pressure is equalized throughout the train, when this valve is returned to its seat by the spring 27. If a very considerable reduction of pressure is made in the chamber A, the piston 18 will move far enough to carry with it the slide valve 23 and allow the air to escape more rapidly by uncovering the two exhaust ports. In case of emergency the handle may be turned to the extreme

Fig. 52



Westinghouse Engineer's Valve.

right, connecting the direct application port with a large exhaust port and releasing the pressure in the brake-pipe with great rapidity.

The Eames Vacuum Brake.

The Eames vacuum automatic brake, as used during the 1886 tests, operated in a reverse way to the Westinghouse. The latter obtains its power from air stored at high pressure in a system of pipes and cylinders, the former obtained its power from the atmospheric pressure upon the exterior of rubber diaphragms, when a vacuum is produced within. The following principal parts of the Eames vacuum brake were thus described:

1. The Ejector, the function of which is to produce a vacuum in the diaphragms.

2. A continuous line of 1¼-in. pipe connecting the ejector with the diaphragms throughout the entire length of the train.

3. The Couplings, which are attached to the end of the flexible hose, and form the connection between the different cars.

4. The Diaphragms, from which the air is exhausted, causing the pressure of the atmosphere to force the rubber disk into the iron shell, and sets the brakes.

5. The Reservoirs, in which a vacuum is maintained, and into which the air in the diaphragms is constantly exhausted by a movement of the ejector lever, or in case of accidental breakage to the trainpipe or couplings.

6. The Valve, which forms the connection between the automatic pipe and the vacuum reservoirs, and between the reservoirs and the diaphragms. Its functions are to control the passage of air from the brake diaphragms to the reservoir and partially or wholly apply the brakes; or to admit air to the brake diaphragms and partially or wholly release the brakes.

The ejector is shown by Figs. 53 and 54. It has two jets, the larger being to produce the required vacuum in the trainpipe and reservoirs, and the smaller to maintain the vacuum against leakage, if any,

in the apparatus. The larger jet is employed only when the immediate creation or restoration of the vacuum is necessary, in charging the train or releasing the brakes. The smaller jet, having a diameter of $\frac{3}{32}$ of an inch, is used continuously, except when the brakes are applied.

The illustration shows the valves in their usual or running position. Steam is admitted at F into the steam chamber surrounding the valve J. In this chamber are two ports, C and D, the former admitting steam to the larger jet, and the latter admitting steam to the smaller jet. The valve J, covering the steam-ports C and D, and the valve H, covering the air-port E, are operated by the same valve-stem, which is connected with the engineer's brake-lever in the cab. In the running position the ports E and C are closed, and D is open. The brake-lever is in the notch in the center of the quadrant to which the lever is attached.

To create a vacuum in the trainpipe and reservoirs (to release the brakes or restore the power after the brakes have been applied), the brake-lever is moved to the forward notch in the quadrant. This opens steam-port C, but does not open port E. Steam passes through port C into the chamber surrounding air-tube A, exhausting the air from trainpipe G through check valve K, creating a vacuum in the reservoirs and trainpipe. At the same time steam is passing through port D into the smaller jet B, which is thus aiding the larger jet in creating the vacuum.

To apply the brakes, air is admitted to the trainpipe. The ejector lever is moved to the rear notch, closing ports C and D, and opening to its full extent port E, through which air is admitted directly to the trainpipe, destroying the vacuum therein. To release the brakes, the lever is returned to the forward notch; uncovering both ports C and D, and closing port E.

To partially apply the brakes, the lever is moved to the second notch in the rear of the running position. This closes port D, and opens the offset shown in the upper-left-hand corner of port E. This admits a small quantity of air to the trainpipe, slightly reducing the vacuum therein, and operating the train valves as hereinafter de-

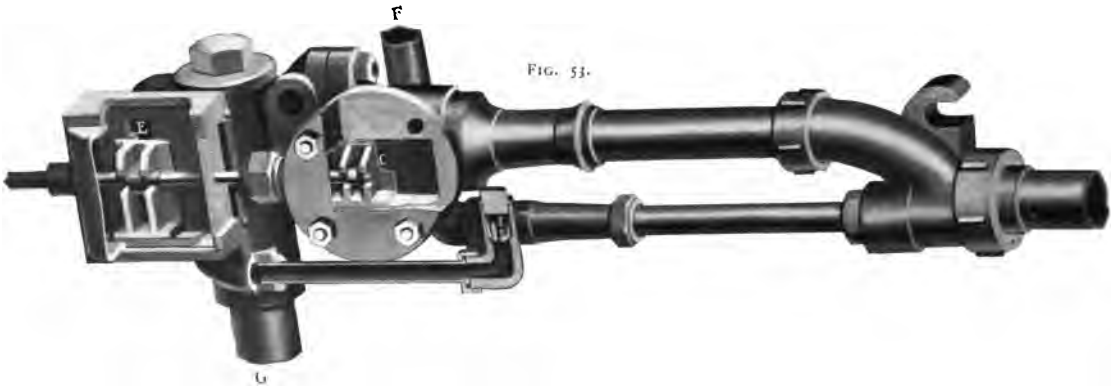


FIG. 53.

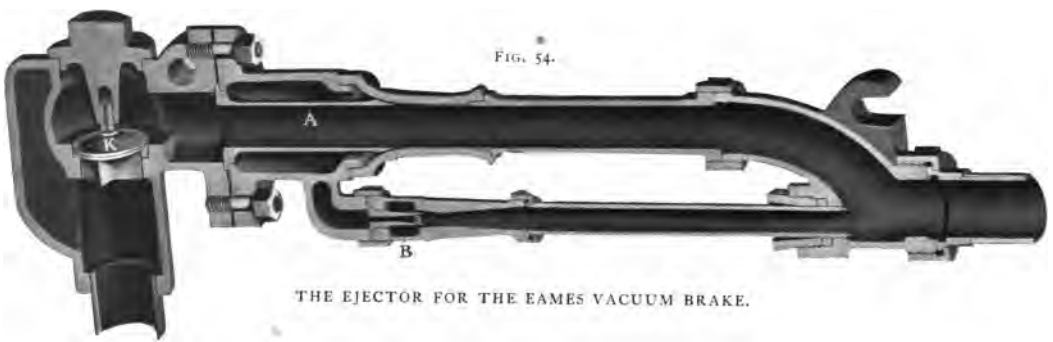


FIG. 54.

THE EJECTOR FOR THE EAMES VACUUM BRAKE.

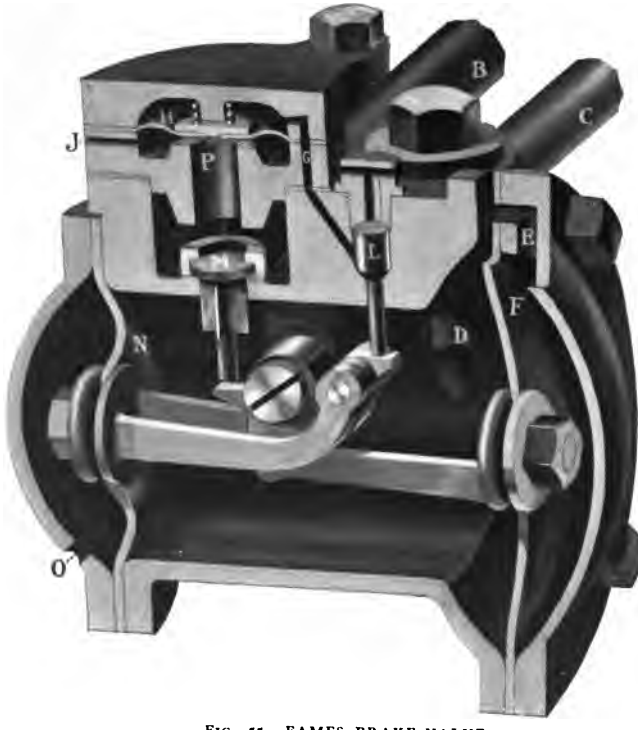


FIG. 55.—EAMES BRAKE VALVE.

scribed. A sufficient amount of air being admitted the brake-lever is moved to the first notch forward of the running position, closing the offset in port E, but not opening port D, thus maintaining in the trainpipe the degree of vacuum resulting from the slight admission of air, until more air is admitted for a further application of the brakes, or the trainpipe is exhausted to release the brakes.

The cut, Fig. 55, shows the valve used in 1887. In the one used in 1886, the release valve was connected directly with the bell-crank and required a greater variation in vacuum to open it. The description applies to both.

The valve is placed between the diaphragms and the reservoir, the reservoir being exhausted through it. Its functions are to control the passage of air from the brake diaphragms to the reservoir, and partially or wholly apply the brakes; also to admit air to the brake diaphragms, and partially or wholly release the brakes. This is accomplished by the valves M and L. These valves are moved by the bell-crank levers shown in the cut, which are controlled by the flexible diaphragms F and N connected with them by links.

A vacuum is maintained in the interior of the valve through check-valve D, which lifts when air is being exhausted from the trainpipe, and closes when air is admitted to it. An equal vacuum is maintained in the chamber outside of diaphragm F, which is connected directly with the trainpipe by passage E above check valve D. The external air is admitted to the outside of diaphragm N through the aperture O. Diaphragm F has, therefore, a vacuum on both sides equal to the vacuum in the trainpipe. Diaphragm N has the same vacuum on the inside, and atmospheric pressure on the outside. The diaphragms differ in size, and the connections with the bell-crank lever are at such angles that, as the bell-crank revolves about its fulcrum, the effective leverage of N increases, while that of F decreases. As the pressures on the two diaphragms are varied, the bell-crank will revolve to a point where the diaphragms balance each other, and are in a state of staple equilibrium. The valve is operated, therefore, by increasing or decreasing the vacuum in the chamber outside of diaphragm F. During the running of the

train, the same vacuum is maintained on both sides of diaphragm F, and the diaphragms and bell-crank assume the position shown in the cut.

In this position the valve L is seated on its upper seat, closing air-port K, and opening communication between the interior of the valve, through passage G, with the chamber above diaphragm H, thus creating a vacuum in this chamber, and lifting diaphragm H from opening P, and permitting the air, through ports J, opening P, and pipe B, to pass to the brake diaphragms, the air having in this manner free access to the brake diaphragms when the brakes are not applied. The valve M is closed, shutting off communication between the brake diaphragms and the reservoir, which is connected with the interior of the valve through a pipe entering the valve on the side towards the reader.

When the brakes are applied, the operation is as follows: Air is admitted to trainpipe C. Check-valve D is seated, cutting off communication between the trainpipe and the interior of the valve. The air flows into the chamber outside of diaphragm F through the passage E, increasing the pressure upon the diaphragm F, and overcoming the resistance of diaphragm N. Diaphragm F moves towards the interior of the valve, causing the bell-crank to revolve away from valve L, which seats itself on its lower seat, cutting off communication between the interior of the valve and the chamber above diaphragm H, through passage G, and admitting the external air to chamber H through port K. This shuts off the communication between the external air and the brake diaphragms through ports J, opening P, and pipe B, by dropping diaphragm H and closing opening P. The movement of the other arm of the bell-crank lifts valve M, opening communication from the brake diaphragms through pipe B with the interior of the valve, and thence to the reservoir, collapsing the brake diaphragms and applying the brakes.

If sufficient air is admitted to the trainpipe to destroy the vacuum therein, the valve M is opened wide, and the brakes are quickly and fully applied. If only a small quantity of air is admitted to the trainpipe, the vacuum outside of diaphragm F is only slightly reduced,

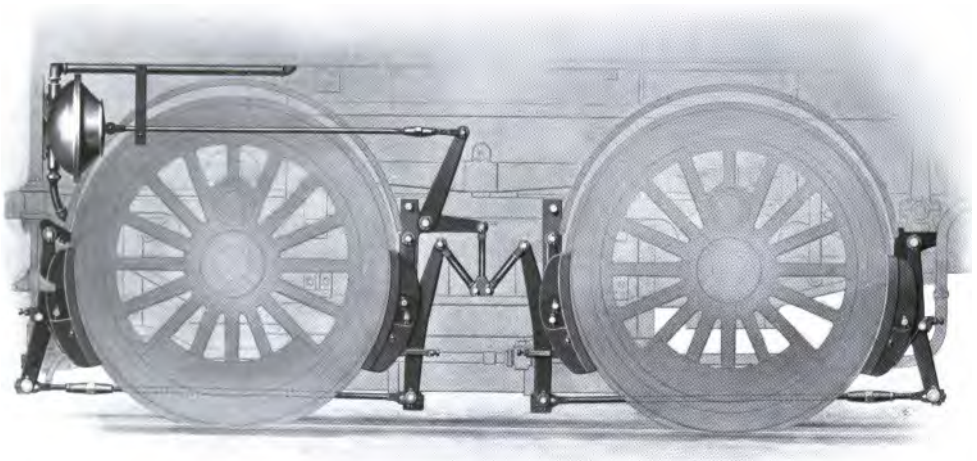


FIG. 56.—EAMES DRIVER BRAKE.

causing diaphragm F to move a proportional distance towards the center of the valve, revolving the bell-crank away from valve L and partially opening valve M. As the air flows from the brake diaphragms into the reservoir, the vacuum in the interior of the valve is reduced, which causes diaphragm F to move gradually toward its normal position, closing valve M, retaining a partial vacuum in the brake diaphragms, and producing a partial application of the brakes. Further slight admission of air to the trainpipe will, in this manner, cause proportionally increased applications of the brakes.

To release the brakes, air is drawn from trainpipe C and the chamber outside of diaphragm F, and also from the reservoir and the interior of the valve, equalizing the vacuum on both sides of diaphragm F, and at the same time restoring the vacuum in the reservoir, which has been partially destroyed by the admission of air from the brake diaphragms. This causes the diaphragm F to return to its normal position, revolving the bell-crank away from valve M (which becomes seated) and raising valve L, thus opening the chamber above H to the vacuum in the reservoir, which raises H and releases the brakes.

Fig. 56 shows the Eames *driver brake* used in the tests. Equal pressure is applied to both sides of all the driving wheels, with the object of avoiding strain upon either the journal or side-rod bearings.

The American Brake.

The American freight-car brake had a centrifugal governor on the axle, which at certain speeds, 11 to 12 miles an hour, moved a forked lever surrounding the axle horizontally, and this, by a mechanical connection, threw in or out of gear a push-bar which was immediately back of the draw-bar, but out of reach of the draw-bar, thus making the brake operative or inoperative, according to the position of this push-bar. Except for this disengaging gear, the American brake was exceedingly simple, consisting of nothing more than a large bent pendant lever, the upper arm of which was bent against the end of the draw-bar, while the lower arm pulled violently on the brake-rod. The push-bar, which the centrifugal governor raised and lowered, was merely a hinged

extension of the upper arm of this lever. The device is shown by Fig. 57. The brake beam, it will be observed, was dropped to the floor, in order to better show the brake rigging. This brake, as with the others coming under the buffer type, could be operated with any form of engine brake. During the trials, the American Brake Company used its own steam-engine brake, which was already successfully introduced on many railroads.

The Widdifield & Button Brake.

The Widdifield & Button was a friction buffer brake, and is shown by Fig. 58. It consisted of a small shaft parallel with the axle, one end of which was carried in a fixed bearing and the other in a lever actuated by the draw-bar on the end of the shaft. Near the movable bearing was a large friction pulley, which bore against a combined soft metal and paper spool on the axle; on the other end of the shaft was the brake chain spool, and beyond that again a ratchet which caused the spool to turn with the shaft when the car was moving forward, but not when backing. This shaft had therefore to be set to work according to the direction in which the train was moving, which could be done from either the top or side of the car by a rod connection; the same motion of the handle set the rod and chain which moved up the friction shaft, so that they also worked only when going forward. This Company made some of its stops with the Westinghouse engine, and others with the Eames engine.

The Rote Brake.

The Rote buffer brake had a centrifugal governor attached to the axle, which, at a certain speed, 4 to 5 miles an hour, allowed the main brake-lever to come in contact with the draw-bar. The brake-lever was connected with the brake-rod by means of a swiveling-piece pivoted on the end of the main brake-lever. As the latter moved, one end of the swiveling-piece came in contact with a fixed wiper, causing the other end to swing around until it was on a dead center with the pivot at the end of the brake-lever, thus taking up a lot of slack without losing

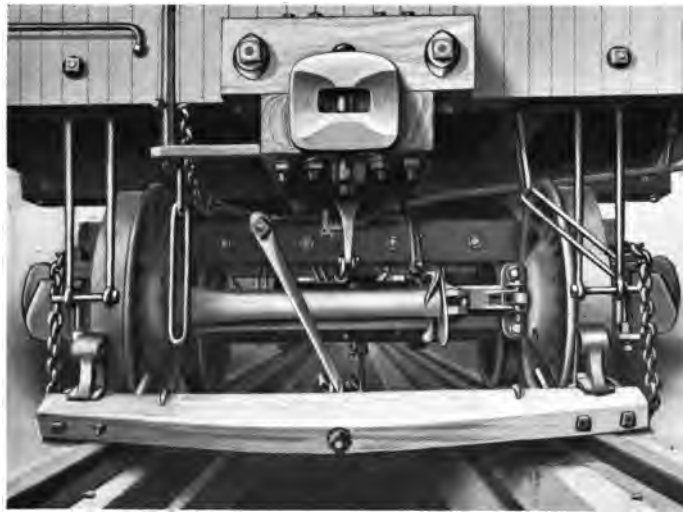


FIG. 57.—THE AMERICAN BRAKE.

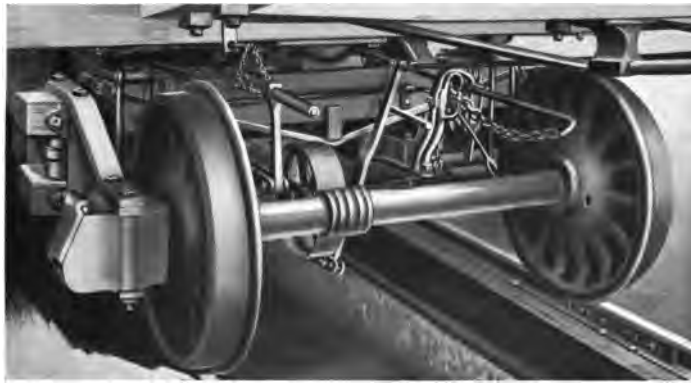


FIG. 58 —THE WIDDIFIELD & BUTTON BRAKE.

THE BURLINGTON BRAKE TRIALS

power. In other words, the power increased as the stroke progressed until it reached 6-in. stroke; after that it remained the same up to 8 in. The general features of the brake are shown by Fig. 59. The parts, as shown, are somewhat displaced by the body of the car being jacked up several inches, removing the bent lever under the body of the car from the bearing which it should have against the vertical lever, as indicated by the dotted line. The Rote Company used the American steam-engine brake and engine during the stops.

Apparatus Used in the Tests.

The speeds at the stop-posts and during the down-grade runs were regulated by means of the Boyer Railway Speed Recorder, of St. Louis, one of which was fitted to each engine.

The device is shown by Fig. 60. By reference to the engraving it will be observed that the machine was contained in a compact oblong cast-iron case, 6 in. wide, 7 in. long and 8 in. high; it weighed about 20 pounds. It was described as follows:

The machine consists principally of a rotary pump, a cylinder and a piston, with mercury as a circulating medium. It is driven at a low rate of speed by a coiled wire belt from the truck axle. A port conveys the current from the pump to the lower end of the cylinder, and another port, whose area is increased or decreased as the piston rises or falls, returns it to the pump. While the machine is at rest the piston is retained in its lowest position by a spring, and the return port is then nearly closed; but, when given motion, the pressure causes the piston to rise until the port is just large enough for the current to escape, thus producing an equilibrium between the tension of the spring and the pressure of mercury; or, in other words, the machine simply weighs the various pressures of mercury produced by the pump, which is in direct proportion to the speed of train.

Attached to the piston-rod, which passes up through the cylinder cover, is a pencil placed in contact with a strip of paper. As the paper is moved in the direction the locomotive travels, the speed in miles per hour, the

distance and the direction of travel, are recorded thereon (the height from the datum line denoting the speed).

The drum which actuates the paper is driven at a uniform rate of speed of ½ in. per mile in the standard machine (those used at brake tests moved paper 2 in. per mile). Gripping rolls hold the paper in contact with the drum, and are so connected that the operation of a lever removes the rolls and pencil from the paper at the same time. The paper is wound on two wooden cores and placed with frictional contact on upright spindles, which form extensions to the rotary pump-shafts and always revolve in one direction. As the locomotive is moved forward or backward the paper is transposed from one spool to the other.

There is also attached to the piston-rod, and carried through a tube, a small wire which operates a gauge with a 5½ in. dial. This gauge is placed in a convenient position in the engine cab, so that the engineer can read at any moment the speed in miles per hour his engine is running.

In the recorders used in 1886, the pump was made to run in whichever way the locomotive moved, and the direction of the current from the pump to the cylinder was controlled by valves. The experience had at Burlington, as well as in shop tests carried on at the same time, demonstrated that this construction could not always be relied upon, on account of leakage of valves. In the machines used in the 1887 tests these valves were discarded and the pump arranged to revolve always in one direction, without regard to the direction in which the locomotive travels. Otherwise the machine was practically the same as that used in 1886. *Facsimiles* of records made by this machine are shown by the speed diagrams in plates VIII. and IX. and Figs. 96 to 99, pages 226 to 229.

The Dynamometer Car used during the brake tests was constructed by the Chicago, Burlington & Quincy Railroad Company in July, 1884, from drawings received from the Pennsylvania Railroad Company. It was 31 ft. long, weighing 31,650 lbs., and was equipped with 2 four-wheel trucks fitted with 33-in. wheels.

The car contained mechanism for recording autographically the train

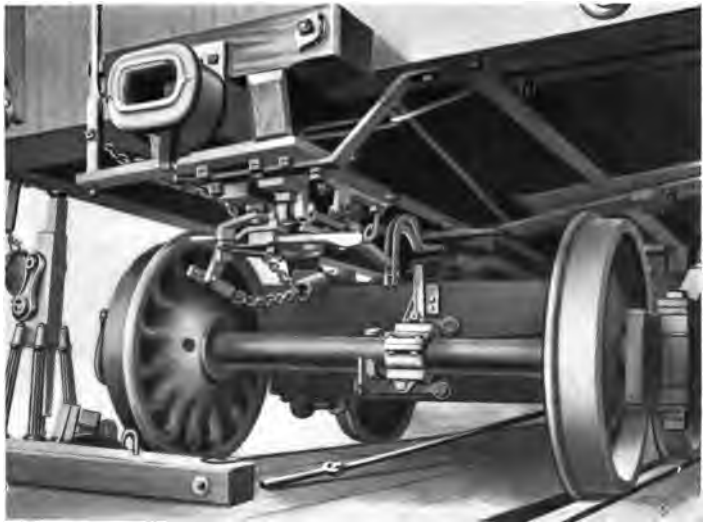


FIG. 59.—THE ROTE BRAKE.

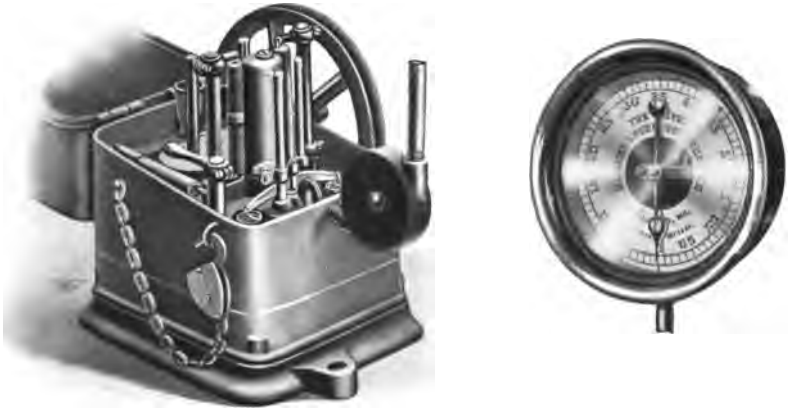


FIG. 60.—BOYER SPEED RECORDER.

resistance and speed at all points in the run. The resistance was obtained by noting the compression of the springs in the dynamometer draw-bar. The motion of these springs was communicated by means of levers to a pen marking on the record-paper, which passed across the dynamometer table at right angles to the motion of the pen. Motion was given to the paper by means of gearing driven by a worm on the rear axle of the forward truck. The speed of the paper was such that 2 ft. of paper corresponded to one mile of track traversed by the car. A stationary pen marked on the paper the datum line. This line coincided with that made by the spring pen when no force was exerted on the draw-bar. When force was exerted, the strain line left the datum, rising above in case of a pull and falling below the datum when a push was exerted on the draw-bar. The distance between the strain and datum lines equals twice the amount of compression of the springs (see plate II.), ½ in. compression giving 1 in. divergence of the lines, corresponding to about 6,000 lbs. pressure.

The speed of the car was obtained by means of a pen attached to the armature of an electro magnet, marking on the paper at intervals of 5 seconds, being connected in the circuit with a clock which completed the circuit at that interval of time. The distance between the successive 5-second marks measured in 30ths of an inch gives the speed in miles per hour. The distance run during the application of the brakes, or any point at which an observation was taken, was obtained by means of a pen similarly connected with an electro-magnet, marking on the paper on the opposite edge to the time-pen upon completing the circuit, by means of a push-button. During the tests this pen was operated by an observer on the engine, electric connection being furnished by means of a cable leading back to the car. The observer marked on the paper the instant brakes were applied and the moment the train was stopped. The distance apart of these points measured in inches and multiplied by 220 (2 ft. to the mile equals 220 ft. to the inch) gave the run in feet. The pens being in line, the speed and train resistance at the instant of application of brakes could be readily observed.

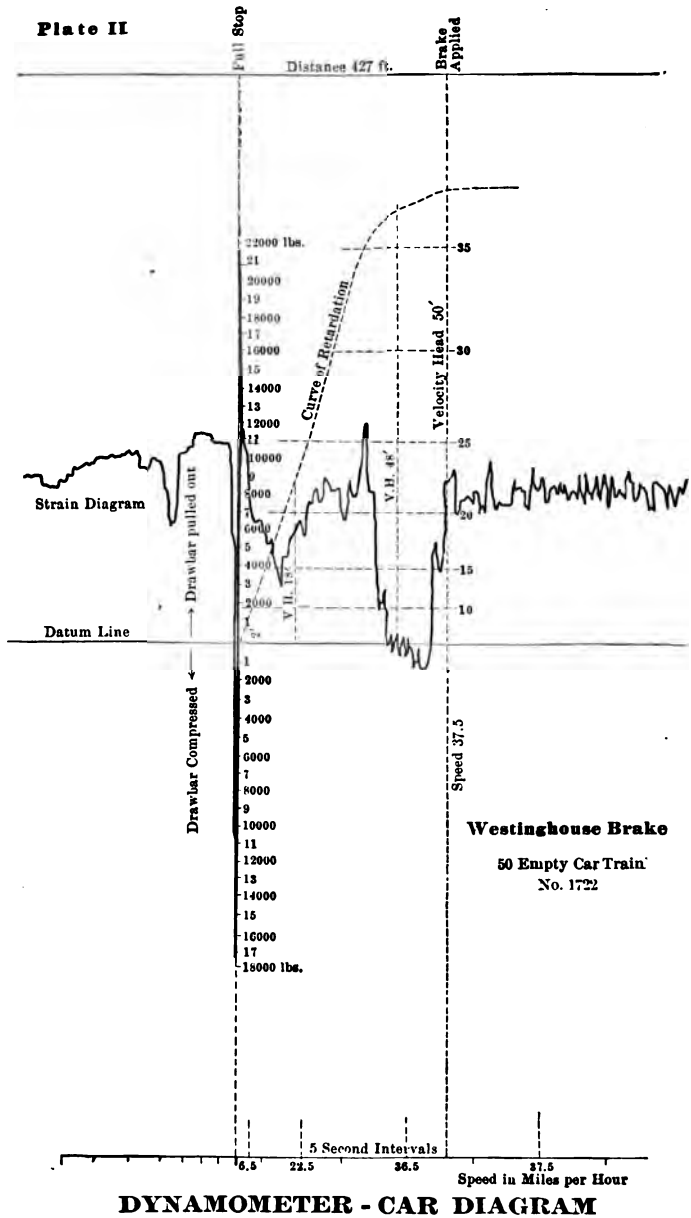
The time between brakes applied and stop was obtained by stop watches, the signals being the motion of the pen operated by the observer on the engine.

Plate II. is a copy of diagrams of stops as recorded by this dynamometer car. These have been selected to illustrate the work of the mechanism just described, for a short time previous to and after a stop as well as during a stop. They show Stop No. 1722, 50 empty car train, Westinghouse electric brake; and No. 1122, 50 mixed car train, Westinghouse electric brake.

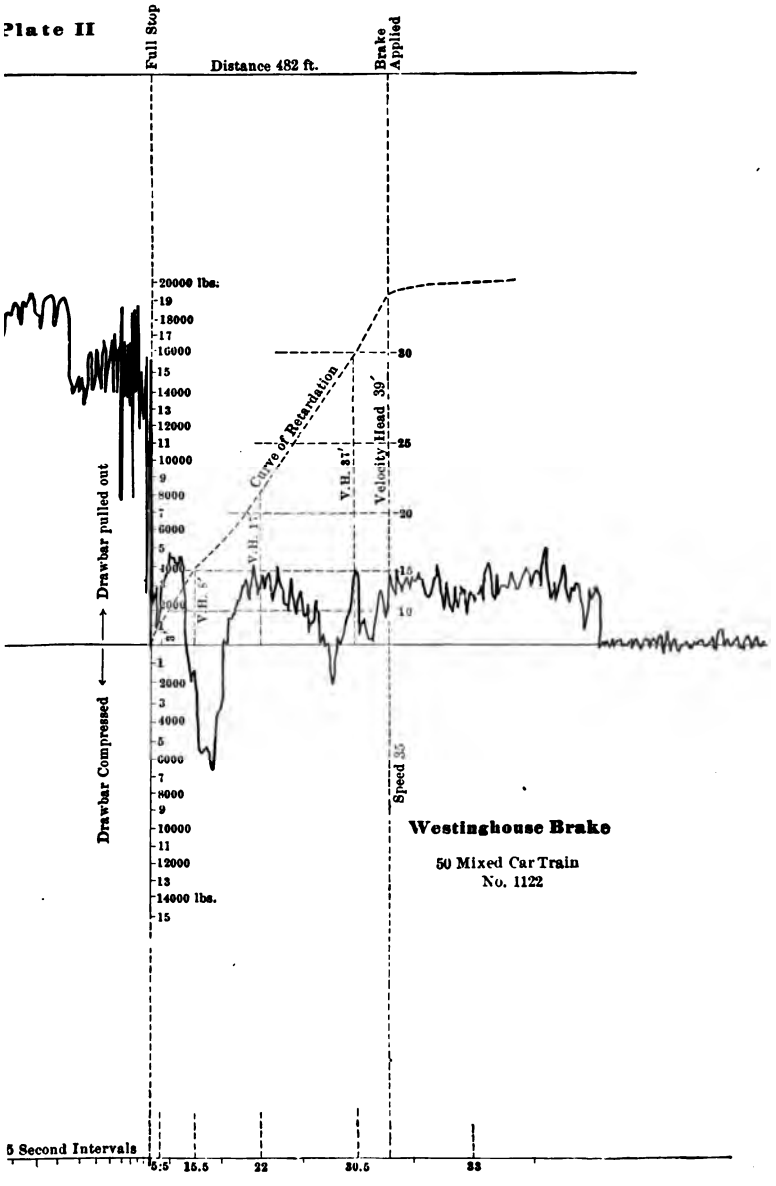
The diagrams also show the method of recording the information obtained. A curve, represented by dotted lines, showing the retarding effect of the brakes, is constructed by erecting at the center of the 5-second intervals an ordinate equal to the "velocity-head" of the train, due to the speed in that interval. The "velocity-head" is the height of the equivalent grade of retardation, or the grade on which, if the train were ascending it without frictional resistance, it would have been stopped by the action of gravity alone in the same distance as it was actually stopped by the brakes and rolling friction. (See editorial in the *Railroad Gazette* of May 15, 1885, on the Calculation of the Efficiency of Brakes, by A. M. Wellington.)

The stops shown indicate the effect of the brakes on light and heavy trains. In the former case the 50 empty car train, in which the brake force approximately equals the train weight, gives a tension diagram during the stop showing that the brakes are effective in holding the train; and the engine brakes being also effective and properly adjusted to the weight braked, hold the engine in a similar way, so that the position of the engine with regard to the train remains the same after the brakes are on as before application. The reverse is shown in the diagrams of the mixed trains, where the train weight being largely in excess of the brake force, causes the cars to run forward on to the engine, compressing the dynamometer draw-bar as indicated.

As a check on the dynamometer record, and for service in case of accident to the regular mechanism, a second means of obtaining data as to distances and speeds was introduced; this was the American District



DYNAMOMETER - CAR DIAGRAM



DYNAMOMETER - CAR DIAGRAM

Telegraph register, with two independent ink-writing pens. In this machine the record was printed on a small paper tape, which was run by clock-work beneath the recording pens, one of which was operated by the observer on the engine, being connected in the same circuit as the distance recording pen of the dynamometer paper, and marked on the tape the points "brakes applied" and "stop." The remaining pen was connected with a circular plate holding 8 contact points, which, as the plate was revolved by means of a belt connection with the front axle of the forward truck, passed under a spring jack, completing the circuit for an instant and causing the pen to make a mark on the tape. The number of these marks or dots included between the points "brakes applied" and "stop" determines the distance run, the distance from the last contact to full stop being noted. The distance between the contact points represented 15.71 ft. of track and also the speed of the car.

The dynamometer paper was run throughout the course, the mile posts being marked thereon for the purpose of checking the speed of the paper; the register-tape was run only during the stops.

The dynamometer records alone were used during the 1886 trials, but in the 1887 tests both the register and dynamometer figures were considered.

The autographic recording apparatus used in the middle car of each train was devised and constructed by the American Brake Company especially for these tests. Its records have been invaluable to the Committee. The device as used in 1886 is shown by Fig. 61, and was thus described at the time:

The various records taken by this single instrument are as follows:

1. Beginning at the left-hand side of the diagram, a Boyer speed indicator, the invention of Mr. Joseph G. Boyer, of St. Louis, Mo., shows the speed in miles per hour on the high dial.

2. The paper roll just below the high dial is fed horizontally at varying rates of speed, at ½-in. per mile for long trips and at about 100 ft. per inch for records designed to cover stops only. The speed is recorded by a diagram on this roll.

3. On this diagram 5-second marks are made by a pencil actuated by an electric circuit from one of the batteries below, passing through the clock and the magnet visible near the top of the high paper roll.

4. The low dial near the front of the table gives the distance run to the nearest foot after the apparatus is thrown into gear, which is done by a handle placed on a shaft seen behind the two battery boxes, and which throws everything on the table into gear at once. One of the hands on the dial makes a complete circuit in 100 ft.; the other moves only one notch for 100 ft., or makes a complete circuit in 10,000 ft.

5. The rod seen running through the floor connects with the brake-rod and actuates directly a pencil, concealed from view by the tall paper roll, which records on the latter continuously (it being fed by the same mechanism which actuates the distance indicator) the tension on the brake-rod, and hence (by multiplying the latter by the proper leverage) the pressure on the brake-beam.

6. Time-marks at 5-second intervals are placed on this diagram also by the same clock, but by an independent circuit.

Thus the four elements of speed, time, distance, and brake-beam pressure are all given and autographically recorded.

In the 1887 tests some slight changes were made in the machine; the speed recorder was combined with the stress indicator, both diagrams being made on the same paper. The motion was transmitted from the axle by a belt made of coiled wire running on adjustable grooved pulleys. The difficulty of slip in the belt connection as used in 1886 was thus in a large measure avoided. Accurately turned steel-tired wheels, without coning, were also used in 1887 under this car, in place of cast-iron wheels as in 1886.

The accompanying diagram, Fig. 62, shows a typical stop from the exceedingly interesting and instructive record obtained from this instrument. The figure represents stop No. 811 of 1887, Carpenter electro-atmospheric brake, emergency stop, 50 empty car train, level track. The record was taken in the 26th car from the engine.

The perpendicular line at the extreme right indicates the moment the

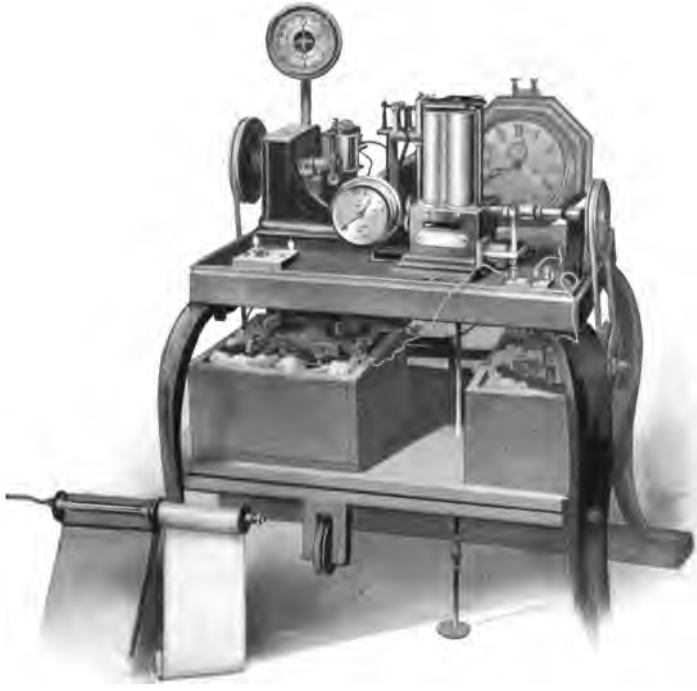
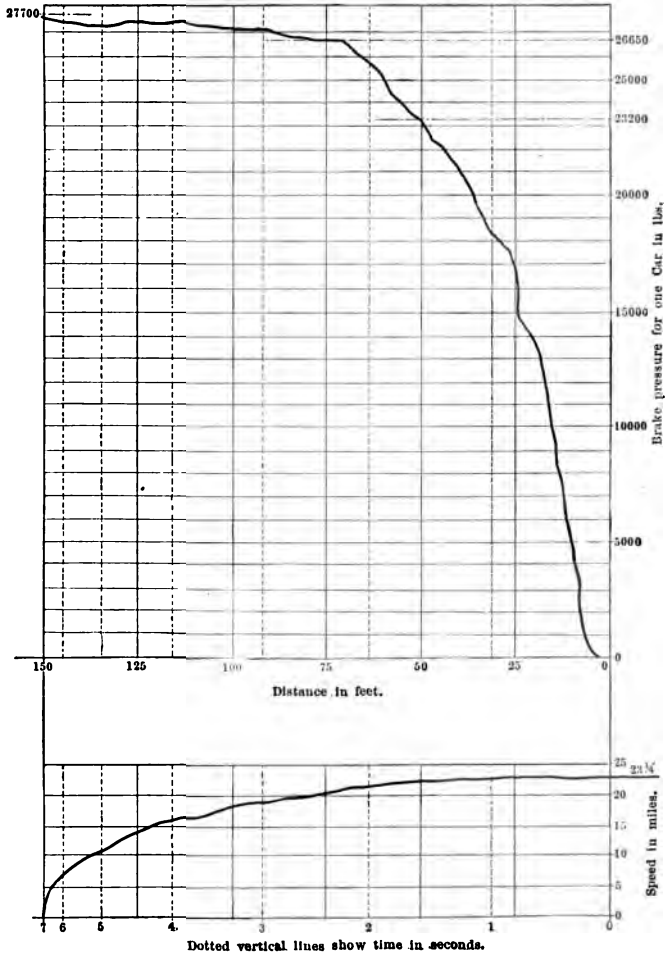


FIG. 61.—THE AUTOGRAPHIC RECORDING APPARATUS.

Fig. 62



Typical Middle Car Diagram.

STOPS No. 1. — Level 20 M. P. H.

Kind of Stop.	Name of Brake	Number of Stop.	Cars Braked and Unbraked.	Weight, Including Engine and all Cars.	Length of Stop Corrected to 20 Mile per Hour.	Actual Records. Speed.	Distance Stopping.	Time Stopping. Seconds.	Shock	Remarks.
General No. 7, Engine Tests	American	741	1	167,300	203	23 3	275	12¼	—	Wherever a — appears under the "Shock" column, it indicates that no slideometer was used. The o indicates that the slide-ometer was used, but gave no movement.
	do.	131	1	167,300	266	26.3	460	18½	—	
	Eames Straight Vacuum	311	1	170,600	272	22.2	335	16¼	—	
	Westinghouse Aut. Air	431	1	169,980	292	22.3	363	16½	—	
	Eames Aut. Vacuum	121	1	170,600	326	23.5	450	20¼	—	
	Westinghouse Aut. Air	111	1	169,980	352	22.	426	20¾	—	
Special No. 3, 25 Mixed Car Train, Engine and 12½ Car-brakes	Westinghouse Service	1541	27	1,281,990	535	26.9	968	35½	3″	
	Eames do.	1511	27	1,283,235	563	22.	681	32½	10 8/16″, 1 5/16″	
	American do.	1731	27	1,366,685	648	22.3	805	37½	1 8/16	
Special No. 3, Emergency Stops, 25 Mixed Car Train, Engine and 12½ Car-brakes	Eames Emergency	1521	27	1,283,235	465	23.	615	30½	18″	
	Westinghouse do.	1551	27	1,281,990	479	24.5	720	30½	8½″	
	Widdifield & Button Emergency	811	27	1,204,160	487	21.9	578	28	One slight bump	
	do. do. do.	821	27	1,204,160	487	22.8	625	30	One slight bump	
	American do.	1741	27	1,366,685	528	24.	760	34½	2⅜	
General Nos. 4, 5, and 8, Emergency Stops, 25 Mixed Car Train, Engine and all Car-brakes, and Engine and Hand-brakes	Westinghouse Emergency	221	27	1,282,430	275	22 1	335	14½	—	
	do. do.	161	27	1,282,430	301	23.	398	18½	—	
	do. do.	211	27	1,282,430	302	21.5	349	15½	—	
	Eames do.	421	27	1,282,910	368	22.2	453	21¾	—	
	Widdifield & Button Emergency	321	26	1,267,040	395	22.5	500	22	—	
	American do.	751	27	1,279,660	405	21.7	476	22½	Two bumps	
	Eames do.	411	27	1,282,910	413	21.4	473	23	—	
	American do.	731	27	1,279,660	417	23.8	591	25¼	Two bumps	
	Eames do.	361	27	1,282,910	448	19.5	426	20½	—	
	American do.	761	27	1,279,660	450	23.2	606	28½	Three bumps	
	Widdifield & Button do.	331	27	1,287,990	457	23.6	636	35	—	
	do. do. do.	341	27	1,287,990	490	22.	593	32½	—	
	do. do. do.	641	27	1,204,160	553	22.2	681	41	—	
	Rote do.	1751	27	1,280,640	648	23.3	880	43½	3 9/16″, 5 8/16″	
	do. do.	1831	27	1,280,640	723	23.7	1,016	50	8/16″, 7/16″	
	C., B. & Q. Hand-brake do.	141	27	1,282,430	810	22.	983	45	—	
	St. L. & S. Frisco do. do.	711	27	1,279,660	955	18.	774	43	—	
	L. V. do. do.	231	26	1,267,040	1,042	20.	1,042	47½	—	

General No. 10, Service Stops, 50 Empty Car Train, Engine and 29½ Car-brakes	Westinghouse Service	1621	51	1,380,102	422	22.5	535	23½	15¼″	
	Eames do.	1761	52	1,246,050	484	21.2	544	23½	37½″, 2″, 5/16″	
	American do.	1841	50	1,576,260	515	18.5	441	25½	18¼″, 18¼″	
	Widdifield & Button Service	1531	52	1,304,394	582	24.2	877	42	32 1/16″, 32″, 4⅛″	
	American do.	1311	50	1,521,094	607	22.	734	34	11″, 13⅛″	
General No. 10, Emergency Stops, 50 Empty Car Train, Engine and 29½ Car-brakes	Westinghouse Emergency	1631	51	1,380,102	313	22.	379	18	49¼″, 7¼″, 4 1/16″	
	Eames do.	1821	52	1,246,050	345	21.	383	19½	45¼″, 2 5/16″	
	American do.	1321	50	1,521,094	396	22.7	511	22	29¾″, 17 1/16″	
	do. do.	1211	50	1,521,094	414	21.5	479	24	2′ 9¼″, 3′ 11¼″	
General Nos. 1*b* and 2*b*, Service Stops, 50 Empty Car Train, Engine and all Car-brakes	Eames Service	1811	52	1,246,050	430	21.5	497	22½	22⅜″	
	American do.	841	43	1,328,013	605	23.2	771	37½	Three bumps	
	Westinghouse Service	631	52	1,404,190	802	22.8	1,041	48½	—	
	do. do.	1721	51	1,380,102	963	20.4	1,005	41½	0	
General Nos. 1*b* and 2*b*, Emergency Stops, 50 Empty Car Train, Engine and all Car-brakes	Westinghouse Emergency	621	52	1,404,190	307	23.5	424	17½	—	
	do. do.	611	52	1,404,190	340	20.3	354	16	—	
	do. do.	1611	51	1,380,102	345	22.0	418	18	18 7/16″	Close coupled.
	Eames do.	521	51	1,383,897	348	22.4	437	19	—	
	do. do.	511	51	1,383,897	383	20.5	414	18	—	
	American do.	831	52	1,576,260	392	20.8	424	25	Three bumps	
	Eames do.	441	51	1,404,810	400	21.	441	18	—	
General Nos. 1*c* and 2*c*, Service Stops, 50 Mixed Car Train, Engine and all Car-brakes	Westinghouse Service	911	52	2,404,190	541	21.2	608	26	5 1/16″	Steam shut off 500 feet before reaching stop-post.
	do. do.	931	51	2,380,102	594	20.7	636	25½	3⅛″	
	Eames do.	1041	50	2,164,234	670	22.2	826	32½	0	
	Westinghouse do.	921	50	2,356,010	703	20.5	739	33	2½″	
	Eames do.	1033	50	2,164,234	710	20.	710	30½	1/16″	
	do. do.	1021	50	2,164,234	861	20.5	905	37½	1 9/16″	
General Nos. 1*a* and 2*a*, Service Stops, 50 Loaded Car Train, Engine and all Car-brakes	Westinghouse Service	1121	52	3,364,190	513	23.5	709	30	11″	Steam shut off 500 feet before reaching stop-post.
	Eames do.	1341	51	3,145,147	766	19.5	728	33	⅜″	
	Westinghouse do.	1141	51	3,260,102	779	19.7	729	34½	0	
	Eames do.	1351	50	3,084,234	795	19.3	740	34½	0	
	do. do.	1331	51	3,145,147	796	21.8	946	42	3⅛″	
	Westinghouse do.	1131	52	3,364,190	1,126	21.5	1,302	48	0	

STOPS No. 2. — Level 40 M. P. H.

Kind of Stop.	Name of Brake.	Number of Stop.	Cars Braked and Unbraked.	Weight, Including Engine and all Cars.	Length of Stop Corrected to 40 Miles per hour.	Actual Records. Speed.	Actual Records. Distance Stopping.	Actual Records. Time Stopping, Seconds.	Shock.	Remarks.
General No. 7, Engine Tests	American	742	1	167,300	833	41.3	889	25	—	
	Westinghouse Straight Air	432	1	169,980	965	39.5	941	27½	—	
	Eames Straight Vacuum	312	1	170,600	1,002	41.3	1,069	32	—	
	American	152	1	167,300	1,193	42.4	1,319	35	—	
	Eames Aut. Vacuum	122	1	170,600	1,303	42.2	1,450	39	—	
	Westinghouse Aut. Air	112	1	169,980	1,457	44.2	1,780	48¾	—	
Special No. 3, 25 Mixed Car Train, Engine and 12½ Car-brakes	Westinghouse Service	1542	27	1,281,990	1,529	40.7	1,652	46	9 7/8″	
	Eames do.	1512	27	1,283,235	2,190	37.	1,874	58½	1¾″	
	American do.	1732	27	1,366,685	2,629	36.	2,130	66	1⅜″, ⅞″	
Special No. 3, Emergency Stops, 25 Mixed Car Train, Engine and 12½ Car-brakes	Westinghouse Emergency	1552	27	1,281,990	1,548	41.8	1,690	47½	9¼″	
	Eames do.	1522	27	1,283,235	1,826	40.5	1,872	57	17¾, 3¼″	
	Widdifield & Button Emergency	822	27	1,204,160	1,892	40.	1,892	56	Two slight bumps	
	do. do. do.	812	27	1,204,160	1,974	38.8	1,858	56¾	0	
	American do.	1742	27	1,366,685	2,227	36.8	1,885	61	5½	
General Nos. 4, 5, and 8, Emergency Stops, 25 Mixed Car Train, Engine and all Car-brakes, and Engine and Hand-brakes	Westinghouse Emergency	222	27	1,282,430	979	40.	979	25½	—	
	do. do.	162	27	1,282,430	991	43.5	1,175	28½	—	
	do. do.	212	27	1,282,430	1,004	40.5	1,029	27½	—	
	Eames do.	422	27	1,282,910	1,553	39.	1,477	43¾	—	
	Widdifield & Button Emergency	322	26	1,267,040	1,570	39.	1,493	49½	—	
	Eames do.	362	27	1,282,910	1,574	37.7	1,399	42¾	—	
	do. do.	412	27	1,282,910	1,632	36.3	1,344	42	—	
	American do.	752	27	1,279,660	1,648	38.	1,487	44½	—	
	do. do.	762	27	1,279,660	1,745	38.7	1,633	50½	One bump	
	Widdifield & Button do.	332	27	1,287,990	1,797	38.8	1,697	49½	—	
	do. do. do.	342	27	1,287,990	1,844	40.5	1,889	64½	—	
	American do.	732	27	1,279,660	1,893	38.1	1,718	51½	Two bumps	
	Widdifield & Button do.	642	27	1,204,160	2,227	39.3	2,150	73	—	
	C., B. & Q. Hand-brake do.	142	27	1,282,430	2,512	42.	2,769	67	—	
	Rote do.	1752	27	1,280,640	2,715	35.8	2,175	75½	4⅞″, 1 5/8″	
	L. V. Hand-brake do.	232	26	1,267,040	2,759	40.	2,759	75½	—	
	St. L. & S. F. H.-brake do.	712	27	1,279,660	3,047	34.5	2,267	72½	—	
	Rote do.	1832	27	1,280,640	3,117	34.7	2,341	81½	1 1/16, ⅛″	

General No. 10, Service Stops, 50 Empty Car Train, Engine and 29½ Car-brakes	Westinghouse Service	1622	51	1,380,102	1,360	38.1	1,232	32	22½″	
	Eames do.	1762	52	1,246,050	1,523	35.7	1,213	34½	27¾″	
	American do.	1842	50	1,576,260	1,571	33.	1,069	35	3½″, 17¼″, 3½″	
	do. do.	1312	50	1,521,094	2,021	35.4	1,583	49	16⅛″, 8¾″, 5/16″, 3/16″	
	Widdifield & Button Service	1532	52	1,304,394	2,564	37.3	2,231	67½	14¾″, 7¾″, 34¼″, ¼″, 3⅛″	
General No. 10, Emergency Stops, 50 Empty Car Train, Engine and 29½ Car-brakes	Westinghouse Emergency	1632	51	1,380,102	1,096	36.8	927	26	4″, 3½″, 1⅝″	
	American do	1322	50	1,521,094	1,488	30.7	877	31½	29⅝″, 9 1/16″	
	. . . . .	. . .	. . .	. . . . .	. . .	. . .	. . .	. . .	. . . . .	
	. . . . .	. . .	. . .	. . . . .	. . .	. . .	. . .	. . .	. . . . .	
General Nos. 1b and 2b, Service Stops, 50 Empty Car Train, Engine and all Car-brakes	Westinghouse Service	1722	51	1,380,102	1,373	37.	1,175	29	8″	
	Eames do.	1812	52	1,246,050	1,576	34.2	1,152	30½	13¼″	
	American do.	842	43	1,328,013	2,110	33 8	1,480	51½	Two bumps	
	Westinghouse do.	632	52	1,404,190	2,562	39.7	2,524	59¼	—	
General Nos. 1b and 2b, Emergency Stops, 50 Empty Car Train, Engine and all Car-brakes	Westinghouse Emergency	622	52	1,404,190	922	40.	922	22½	—	
	do. do.	612	52	1,404,190	927	40.	927	22¼	—	
	do. do.	1612	51	1,380,102	983	39.5	959	23½	15¾″	Close coupled.
	Eames do.	522	51	1,383,897	1,143	37.7	1,016	28¼	—	
	do. do.	512	51	1,383,897	1,220	37.2	1,055	29¾	—	
	do. do.	442	51	1,404,810	1,339	37.	1,120	31½	—	
	. . . . .	. . .	. . .	. . . . .	. . .	. . .	. . .	. . .	. . . . .	
General Nos. 1c and 2c, Service Stops, 50 Mixed Car Train, Engine and all Car-brakes	Westinghouse Service	932	51	2,380,102	1,398	39.	1,329	30½	. . . . .	Steam shut off 1,000 feet before reaching stop-post.
	do. do.	922	50	2,356,010	1,568	39.4	1,522	37	1/16″	
	do. do.	912	52	2,404,190	1,649	39.3	1,592	Lost.	2¼″	
	Eames do.	1042	50	2,164,234	2,044	35.5	1,610	46½	7½″	
	do. do.	1022	50	2,164,234	2,127	35.	1,667	49	1/16″, 13⅜″, 5/16″	
	. . . . .	. . .	. . .	. . . . .	. . .	. . .	. . .	. . .	. . . . .	
General Nos. 1a and 2a, Service Stops, 50 Loaded Car Train, Engine and all Car-brakes					30 miles per hour.					
	Westinghouse Service	1122	52	3,364,190	907	38.	1,455	38	3/16″	Steam shut off 1,000 feet before reaching stop-post.
	do. do.	1132	52	3,364,190	938	36.6	1,396	36	¼″	
	do. do.	1142	51	3,260,102	1,069	30.5	1,255	37	0	
	Eames do.	1342	51	3,145,147	1,444	29.8	1,425	49½	3/16″ bump after warning signal . . . . 5/16″ bump after stop signal	
	do. do.	1352	50	3,084,234	1,483	29.4	1,423	50½	¼″, 1/16″	
	do. do.	1332	51	3,145,147	1,498	32.3	1,733	55½	3/16″, 5/16″, 2 1/16″ 4½″	

STOPS No. 3. — 53 Feet Grade, 20 M. P. H.

Kind of Stop.	Name of Brake.	Number of Stops.	Cars Braked and Unbraked.	Weight, Including Engine and all Cars.	Length of Stop Corrected to 20 Mls. per Hour.	Actual Records. Speed.	Distance Stopping.	Time Stopping. Seconds.	Shock.	Remarks.
General No. 7, Engine Tests	American	743	1	167,300	272	19.3	253	13¾	—	
	Eames Straight Vacuum	313	1	170,600	282	23.4	387	21¼	—	
	Westinghouse Straight Air	433	1	169,980	308	23.5	425	21½	—	
	American	133	1	167,300	329	23.5	454	22¼	—	
	Eames Aut. Vacuum	123	1	170,600	344	26.8	619	28	—	
	Westinghouse Aut. Air	113	1	169,980	372	21.7	438	21	—	
Special No. 3, 25 Mixed Car Train, Engine and 12½ Car-brakes	Westinghouse Service	1543	27	1,281,990	543	26.6	960	37½	7¾″	
	Eames do.	1513	27	1,283,235	900	20.7	964	45½	0	
	American do.	1733	27	1,366,685	919	24.5	1,379	59½	1⁄8″	
Special No. 3, Emergency Stops, 25 Mixed Car Train, Engine and 12½ Car-brakes	Westinghouse Emergency	1553	27	1,281,990	478	23.6	666	31	10¼″	
	Eames do.	1523	27	1,283,235	526	22.	636	36	22 1⁄16″	
	Widdifield & Button Emergency	823	27	1,204,160	613	24.4	913	40	One slight bump	
	do. do. do.	813	27	1,204,160	725	21.0	800	39½	0	
	American do.	1743	27	1,366,685	838	23.8	1,184	52½	6⅛″	
General Nos. 4, 5, and 8, Emergency Stops, 25 Mixed Car Train, Engine and all Car-brakes, and Engine and Hand-brakes	Westinghouse Emergency	213	27	1,282,430	307	21.7	361	17¼	—	
	do. do.	163	27	1,282,430	317	22.4	398	18	—	
	do. do.	223	27	1,282,430	320	20.	320	14½	—	
	Eames do.	413	27	1,282,910	485	20.	485	25¼	—	
	do. do.	423	27	1,282,910	486	20.5	511	27	—	
	do. do.	763	27	1,279,660	497	21.	548	29	Four bumps	
	Widdifield & Button Emergency	343	27	1,287,990	498	21.	549	26	—	
	do. do. do.	323	26	1,267,040	500	21.7	588	39	—	
	American do.	753	27	1,279,660	509	22.2	628	30¼	Two bumps	
	Eames do.	363	27	1,282,910	514	21.4	588	28¼	—	
	American do.	733	27	1,279,660	525	23.5	725	37	Four bumps	
	Widdifield & Button do.	333	27	1,287,990	556	20.3	573	27¼	—	
	C., B. & Q. Hand-brake do.	143	27	1,282,430	923	21.6	1,076	48	—	
	Rote do.	1833	27	1,280,670	955	21.6	1,119	67	2½″	
	Widdifield & Button do.	643	27	1,204,160	1,012	22.4	1,270	71	—	
	Rote do.	1753	27	1,280,640	1,054	24.1	1,207	64	4 1⁄16″	
	L. V. Hand-brake do.	233	26	1,267,040	1,074	20.	1,074	49	—	
	St. L. & S. F. H.-brake do.	713	27	1,279,660	1,120	22.3	1,392	63	—	

General No. 10, Service Stops, 50 Empty Car Train, Engine and 29½ Car-brakes	Westinghouse Service	1623	51	1,380,102	504	22.5	639	26½	16½″	
	American do.	1843	50	1,576,260	528	21.5	726	31	14½″, 3⅜″	
	Eames do.	1763	52	1,246,050	614	20.	614	28	15¼″	
	Widdifield & Button Service	1533	52	1,304,394	650	21.2	731	34	15⅛″, 36″, ⅛″, 13¼″	
	American do.	1313	50	1,521,094	747	23.6	1,040	40	¼″, ⅜″	
General No. 10, Emergency Stops, 50 Empty Car Train, Engine and 29½ Car-brakes	Westinghouse Emergency	1713	51	1,380,102	442	20.2	451	21	24½″	
	American do.	1213	49	1,521,094	449	22.3	558	31	23⅜″, ⅛″, 3⅛″, ¼″	
	do. do.	1323	50	1,521,094	452	24.1	657	29	28⅜″, 18¾″	
	. . . . .	. . .	. .	. . . . .	. . .	. . .	. . .	. . .	. . . . .	
General Nos. 1*b* and 2*b*, Service Stops, 50 Empty Car Train, Engine and all Car-brakes	Westinghouse Service	1723	51	1,380,102	752	22.4	944	33	7¼″	
	American do.	843	43	1,328,013	757	23.2	1,019	47	Two lurches, two bumps	
	Eames do.	1813	52	1,246,050	757	21.3	859	33½	14⅛″	
	Westinghouse do.	633	52	1,404,190	1,677	22.3	2,077	76½	—	
General Nos. 1*b* and 2*b*, Emergency Stops, 50 Empty Car Train, Engine and all Car-brakes	Westinghouse Emergency	1613	50	1,356,012	303	26.	513	17½	19⅜″	Close coupled.
	do. do.	623	51	1,380,102	323	23.	427	17¼	—	
	do. do.	613	52	1,404,190	326	23.	431	17½	—	
	Eames do.	523	51	1,383,897	339	22.	448	18	—	
	do. do.	513	51	1,383,897	376	23.	497	20	—	
	do. do.	443	51	1,404,810	389	23.2	524	19	—	
	American do.	833	52	1,576,260	427	20.4	445	24½	Three bumps	Steam shut off 500 feet before reaching stop-post.
General Nos. 1*c* and 2*c*, Service Stops, 50 Mixed Car Train, Engine and all Car-brakes	Westinghouse Service	933	51	2,380,102	400	24.5	600	24¼	1½″*	Steam shut off 500 feet before reaching stop-post.
	do. do.	923	50	2,356,010	492	23.1	655	26¾	. . . . .	
	do. do.	913	52	2,404,190	609	22.5	772	Lost.	¾″	
	Eames do.	1033	50	2,164,234	761	22.7	994	39½	8½″, 4⅞″	
	do. do.	1043	50	2,164,234	785	22.3	976	39½	9⅜″	
	do. do.	1023	50	2,164,234	915	21.9	1,097	42¾	7⅛″, ⅜″	
General Nos. 1*a* and 2*a*, Service Stops, 50 Loaded Car Train, Engine and all Car-brakes	Westinghouse Service	1123	52	3,364,190	609	23.4	834	30	1⅛″	Steam shut off 500 feet before reaching stop-post.
	do. do.	1143	51	3,260,102	648	23.3	871	32½	¼″	
	do. do.	1133	52	3,364,190	675	24.4	915	31½	1⅞″	
	Eames do.	1343	51	3,145,147	797	22.8	1,036	40	⅜″, 2⅜″	
	do. do.	1353	50	3,084,234	865	21.8	1,009	45½	⅜″, 2⅛″	
	do. do.	1333	51	3,145,147	1,014	24.7	1,544	62	2⅜″, 3¼″, ⅞″	

* In No. 933 stop the Z car broke down, and the speeds given are uncertain.

STOPS No. 4. — 53 Feet Grade, 40 M. P. H.

Kind of Stop.	Name of Brake.	Number of Stop.	Cars Braked and Unbraked.	Weight, Including Engine and all Cars.	Length of Stop Corrected to 40 Mls. per Hour.	Actual Records. Speed.	Distance Stopping.	Time Stopping. Seconds.	Shock.	Remarks.
General No. 7, Engine Tests	American	744	1	167,300	1,041	37.7	925	26½	—	
	Eames Straight Vacuum	314	1	170,600	1,178	42.6	1,336	40	—	
	Westinghouse Straight Air	434	1	169,980	1,207	42.	1,331	36½	—	
	American	134	1	167,300	1,396	39.8	1,382	40	—	
	Eames Aut. Vacuum	124	1	170,600	1,633	41.	1,716	46½	—	
	Westinghouse Aut. Air	114	1	169,980	2,039	46.8	2,792	70	—	
Special No. 3, 25 Mixed Car Train, Engine and 12½ Car-brakes	Westinghouse Service	1544	27	1,281,990	2,506	41.3	2,672	71	8⅝″	
	Eames do.	1514	27	1,283,235	3,541	40.8	3,684	100	0.	
	American do.	1734	27	1,366,685	4,568	41.5	4,917	136	2⅛″	
Special No. 3, Emergency Stops, 25 mixed Car Train, Engine and 12½ Car-brakes	Westinghouse Emergency	1554	27	1,281,990	2,056	40.	2,056	59	8⅞″	
	Eames do.	1524	27	1,283,235	3,094	39.5	3,017	90½	14⅛″	
	Widdifield & Button Emergency	814	27	1,204,160	3,108	42.8	3,565	94½	0.	
	do. do. do.	824	27	1,204,160	3,309	41.3	3,730	99½	One slight bump	
	American do.	1744	27	1,366,635	4,159	40.9	4,341	119	7½″, 1/16″	
General Nos. 4, 5, and 8, Emergency Stops, 25 Mixed Car Train, Engine and all Car-brakes, and Engine and Hand-brakes	Westinghouse Emergency	164	27	1,282,430	1,088	46.8	1,490	34¾	—	
	do. do.	214	27	1,282,430	1,155	45.	1,462	34.	—	
	do. do.	224	27	1,282,430	1,296	44.	1,506	35	—	
	Eames do.	414	27	1,282,910	2,033	39.7	2,002	57½	—	
	do. do.	424	27	1,282,910	2,056	43.8	2,465	66¾	—	
	Widdifield & Button Emergency	334	27	1,287,990	2,346	42.2	2,612	75	—	
	C., B. & Q. Hand-brake do.	144	27	1,282,430	2,530	45.4	3,259	69½	-	
	Widdifield & Button do.	324	26	1,267,040	2,543	41.8	2,781	83	—	
	Eames do.	364	27	1,282,910	2,594	41.7	2,811	74½	—	
	American do.	764	27	1,279,660	2,640	41.	2,774	75	Two bumps	
	do. do.	734	27	1,279,660	2,718	42.3	3,040	82½	Three slight, one severe shock	
	do. do.	754	27	1,279,660	2,749	40.1	2,763	75	0.	
	Widdifield & Button do.	344	27	1,287,990	2,821	41.3	3,008	94½	—	
	L. V. Hand-brake do.	234	26	1,267,040	3,493	40.	3,493	81	—	
	Widdifield & Button do.	644	27	1,204,160	3,572	42.5	4,033	109½		
	St. L. & S. F. H.-brake do.	714	27	1,279,660	4,672	37.3	4,063	104		
	Rote do.	1754	27	1,280,640	4,980	40.	4,980	130	5″, 1/16″	Hand-brakes called for passing distance post.
	do. do.	1834	27	1,280,640	5,376	40.7	5,566	137	4¾″	

General No. 10, Service Stops, 50 Empty Car Train, Engine and 29½ Car-brakes	Westinghouse Service	1624	51	1,380,102	1,256	39.7	1,238	33	43 1/16", 1/4"	
	Eames do.	1764	52	1,246,050	1,875	38.6	1,709	44	35 3/16", 1/8"	
	American do.	1844	50	1,576,260	1,941	40.	1,941	51½	26 1/4", 24 3/16"	
	do. do.	1314	50	1,521,094	2,777	37.1	2,389	64	3/4", 3/16"	
	Widdifield & Button Service	1534	52	1,304,394	4,479	40.5	4,592	125	14 bumps, varying from 1/16" to 14 3/16"	
General No. 10, Emergency Stops, 50 Empty Car Train, Engine and 29½ Car-brakes	Westinghouse Emergency	1714	51	1,380,102	1,259	37.	1,077	30½	45 1/16", 3/16," 1/8"	
	American do.	1324	50	1,521,094	2,139	39.	2,024	56	37 1/2", 8 7/16"	
	do. do.	1214	49	1,521,094	2,160	37.3	1,880	54¼	2' 8½", 4½"	
	. . . . .	. . .	. .	. . . . .	. . .	. . .	. . .	. . .	. . . . .	
General No. 1*b* and 2*b*, Service Stops, 50 Empty Car Train, Engine and all Car-brakes	Eames Service	1814	52	1,246,050	1,850	39.4	1,572	39	25 5/16"	
	Westinghouse Service	1724	51	1,380,102	1,860	38.4	1,712	34½	6"	
	do. do.	634	52	1,404,190	2,314	38.3	2,059	46¼	—	
	American do.	844	43	1,328,013	2,777	41.0	2,919	82	0	
General Nos. 1*b* and 2*b*, Emergency Stops, 50 Empty Car Train, Engine and all Car-brakes	Westinghouse Emergency	1614	50	1,356,012	957	43.	1,106	25	21 3/8	Close coupled.
	do. do.	624	51	1,380,102	966	43.	1,116	24½	—	
	do. do.	614	52	1,404,190	1,020	41.6	1,104	Lost.	—	
	Eames do.	524	51	1,383,897	1,364	40.5	1,399	35¼	—	
	do. do.	514	51	1,383,897	1,370	40.6	1,416	38	—	
	do. do.	444	51	1,404,810	1,563	39.	1,486	39½	—	
	American do.	834	52	1,576,260	2,554	34.4	1,901	65	Bumps	Steam shut off 1,000 feet before reaching stop-post.
General Nos. 1*c* and 2*c*, Service Stops, 50 Mixed Car Train, Engine and all Car-brakes	Westinghouse Service	924	50	2,356,010	1,535	43.9	1,811	41¼	5/16"	Steam shut off 1,000 feet before reaching stop-post.
	do. do.	914	52	2,404,190	1,649	41.6	1,787	Lost.	1/8"	
	do. do.	934	51	2,380,102	1,694	41.5	1,823	40	1/2"*	
	Eames do.	1034	50	2,164,234	2,746	38.2	2,505	65	3½"	
	do. do.	1044	50	2,164,234	2,757	40.	2,757	73	4 3/4"	
	do. do.	1024	50	2,164,234	3,665	40.0	3,666	90½	1 3/16"	
General Nos. 1*a* and 2*a*, Service Stops, 50 Loaded Car Train, Engine and all Car-brakes					30 miles per hour.					
	Westinghouse Service	1124	52	3,364,190	1,119	39.7	1,959	47	9 1/8"	Steam shut off 1,000 feet before reaching stop-post.
	do. do.	1134	52	3,364,190	1,360	37.	2,065	50½	15 5/16"	
	do. do.	1144	51	3,260,102	1,502	35.4	2,092	52	1 7/16"	
	Eames do.	1344	51	3,145,147	1,680	32.	1,908	64½	0	
	do. do.	1354	50	3,084,234	1,921	34.8	2,688	84½	13 3/16"	
	do. do.	1334	51	3,145,147	2,096	34.2	2,724	86½	13 1/16", 1"	

* Z car broke down, and speeds given are uncertain.

engineer received signal to apply brakes. The curved line of the upper diagram shows the pressure of the brakes upon the wheels, the horizontal parallel lines indicating the pressure in steps of 1,000 lbs.; the full perpendicular lines give each 25 ft. of the stop, while the dotted perpendiculars indicate the time in one-second intervals.

The curve in the lower diagram shows the speed, giving the gradual decrease at all points until the stop is made. The horizontal parallel lines in this case indicate the speed in miles per hour, while the full and dotted perpendiculars have the same signification as in the upper diagram. It will be observed from this diagram that with an initial speed of 23¼ miles an hour, in 7 seconds a 50-car train was stopped in 150 ft.

The Tests.

The tests were formally opened July 13th, and continued without interruption until August 3d.

Tabulated Statements.

The results are shown in the series of tables just given.

Series B, 1886, plate III., groups the stop tests of the different competitors under each competition, ranking them in their order of shortness of stop corrected to a uniform speed. The inequalities of the brake gear are not taken into computation. Data is given on page 149, under the heading of "Foundation Gear," which will enable those desiring to do so to work out the possibilities under other conditions of foundation gear. On this table the "kind of stops" are placed in accordance with their importance, viz.: the 25-car trains appear first, then the 50-car train, with brakes used on the forward 30 cars only, and finally the 50-car train, with brakes on all cars, ranking the empty train first, then the mixed train, and, lastly, the loaded train. It will be observed the representatives of the independent brakes quickly dropped out of all tests requiring consecutive braking on more than 30 cars. The American made one trip over the course, with brakes on 50 empty cars, but quickly succumbed, leaving the field undisputed to the continuous brakes represented by the Eames and the Westinghouse.

AVERAGE RESULTS FROM 1886 BRAKE TESTS.

The distances corrected for the exact speeds noted, but not for level grade.

Kind of Stop.	Name of Brake.	Speed. Miles.	Stops Made on: Distance. Feet. Level.	Stops Made on: Distance. Feet. 51 feet Grade.	Time: From Brakes Applied by Engineer. Rear Car. Brakes Begin to Apply. Seconds.	Time: From Brakes Applied by Engineer. Rear Car. Brakes Fully on. Seconds.	Time: From Full Stop. Brakes Off. Seconds.	Time: From Full Stop. Train Moving. Seconds.	Train. Total Weight — Engine, Cars and Load. Tons.	Train. Per Cent. Braked.	Pressures. Before Stop, Triple-jet. Average, Front End and Rear End. Lbs.	Pressures. Cylinder, Rear Car. Lbs.	Pressures. Middle Car Brake Beam Pressure, Per Cent. Weight of Empty Car.	Miscellaneous. Movement of Slidometer, Rear Car, Least and Greatest. Inches.	Miscellaneous. Coupings Broken.
25 mixed cars, General Tests Nos. 4, 5, and 8, Emergency	Westinghouse	20	293	315	3¼	—	14⅗	21½	641.21	54.5	60½	38⅗	—	—	0
		40	691	1,179	3	—	17⅗	22	641.21	54.5	64½	41⅗	—	—	0
	Eames	20	409	495	—	6	14	19½	641.45	48.4	6⅜	5¾	55½	—	1
		40	1,586	2,228	—	5¾	53½	60	641.45	48.4	6⅜	5¾	54⅗	—	2
	American	20	457	510	6½	Not fully applied.	—	11½	639.83	61.0	—	—	—	1–4 bump	0
		40	1,762	2,702	5½		—	13	639.83	61.0	—	—	—	1–4 bump	1
	Widdifield & Button	20	474	641	6½		—	9¾	630.9	47.2	—	—	—	—	0
		40	1,859	2,820	6½		—	46¼	630.9	47.2	—	—	—	—	2
	C., B. & Q. Handbrake	20	810	923	—	—	—	—	641.21	55.4	—	—	—	—	0
		40	2,512	2,530	—	—	—	—	641.21	55.4	—	—	—	—	0
	Lehigh Valley Handbrake	20	1,042	1,074	—	—	—	—	633.52	48.2	—	—	—	—	0
		40	2,759	3,493	—	—	—	—	633.52	48.2	—	—	—	—	0
	Rote	20	685	1,056	10	Not fully applied.	—	16¾	640.35	54.3	—	—	47	⅛″ to 5⅛″	0
		40	2,916	*5,178	7½		—	17½	640.35	54.3	—	—	48	1⅛″ to 5″	0
	St. L. & San Francisco Handbrake	20	955	1,120	—	—	—	23	639.83	62.3	—	—	—	—	0
		40	3,047	4,672	—	—	—	59¾	669.83	62.3	—	—	—	—	0
50 empty cars, General Tests 1*b* and 2*b*, Service	Eames	20	430	757	18	20	31½	84½	623.02	91.8	6¾	6⅛	63½	14⅛″ to 22⅜″	0
		40	1,576	1,850	12¼	18½	32	61½	623.02	91.8	6½	5⅞	59	13¾″ to 25⅛″	0
	Westinghouse	20	882	1,214	24¾	36⅛	11¾	33	646.07	92.55	62	16¼	25	0″ to 7¼″	0
		40	1,967	2,087	12¾	25⅞	13⅜	30½	646.07	92.55	61⅜	26	53	6″ to 8″	1
	American	20	605	757	11	Not fully on.	—	22¼	644.	92.	—	—	—	4 bumps	0
		40	2,110	2,777	10		—	1 m. 38⅞ s.	644.	92.	—	—	—	4 bumps	0
50 empty cars, General Tests 1*b* and 2*b*, Emergency	Westinghouse	20	331	317	7¾	12	17	41½	694.11	92.5	62	30⅘	31	18⅛″ to 19⅜″	0
		40	944	981	7½	11¾	17⅗	10 m. 7 s.	694.11	92.5	62¼	39⅗	59.7	15¾″ to 21⅜″	0
	Eames	20	377	368	—	11	55⅓	6 m. 56½ s.	702.40	79.9	6¾	6	50	. . . . .	7
		40	1,238	1,432	—	11¾	28⅗	2 m. 51½ s.	702.40	79.9	6⅜	5¾	47.7	. . . . .	5
	American	20	392	427	9	Not fully applied.	—	26½	788.13	93.3	—	—	—	1 bump	1
		40	—	2,554	10½		—	18	788.13	93.3				2 bumps	0
50 mixed cars, General Tests 1*a* and 2*a*, Service	Westinghouse	20	613	500	9⅜	15¼	13¾	1 m. 11¼ s.	1,188.38	53.5	62½	28⅛	26.5	⅛″ to 5⅛″	1
		40	1,538	1,626	9	16	58⅓	1 m. 45½ s.	1,188.38	53.5	62	36¾	54	⅛″ to 2¼″	0
	Eames	20	747	820	15¾	19¾	21¾	2 m. 30¾ s.	1,082.11	50.9	6⅜	5⅜	54½	⅛″ to 9⅜″	2
		40	2,085	2,723	16	20½	23	1 m. 20 s.	1,082.11	50.9	6¾	5⅜	52⅗	⅛″ to 13⅛″	1
50 loaded cars, General Tests 1*a* and 2*a*, Service	Westinghouse	20	513	644	10	19	13¾	57½	1,664.74	38.7	66	39	46.7	1″ to 11″	0
		30	971	1,327	10½	19	59	1 m. 30 s.	1,664.74	38.7	66½	41⅗	65	0″ to 15⅛″	1
	Eames	20	786	892	11½	15½	31	61¾	1,562.42	35.7	6⅜	5¾	55	0″ to 3¼″	2
		30	1,475	1,899	10½	16	26½	64¾	1,562.42	35.7	6⅜	5¾	52.5	1″ to 13⅜″	2

NOTE.—Under column "Movement of Slidometer" when a — appears it indicates that no slidometer was used. The o indicates that the slidometer was used, but gave no movement.

* Handbrakes called for in stop 1834.

Series C, 1886, plate IV., has been prepared with a view to showing in a more condensed table the general results of the tests. The following stops have been averaged, correcting for the exact speeds, but not for grades :

25	mixed car trains—	all brakes	. . . . .	Emergency.
50	empty do.	do.	. . . . .	Service.
50	do. do.	do.	. . . . .	Emergency.
50	mixed do.	do.	. . . . .	Service.
50	do. do.	do.	. . . . .	Emergency.

A notable feature on this table is that the hand brakes used on the Chicago, Burlington & Quincy and the Lehigh Valley trains show a higher efficiency than the Rote automatic brake.

Slideometer.

On each of the previously mentioned tables a column will be observed headed "Movement of Slideometer, Rear Car, Inches."

At an early stage of the tests the unlooked-for shocks in the rear car made it evident to the Committee that an exceedingly important element in a long train contest was not provided with any registering device. The want of such a device became all the more apparent with the 50-car trains, which, it was estimated, increased the violence of any particular shock in a greater ratio than the square of the number of cars added.

Moreover, each individual was more or less influenced in his sense of any given shock by his preparation to receive it, in person as well as in mind. The sliding movements of some of the tool boxes and loads during the earlier stops suggested to the referee the impact gauge, or "Slideometer," as it was immediately named. On the 9th morning of the test the Slideometer was first used, and its records at once became one of the most important during the contest.

The device consists of a wooden trough 14 ft. long by 6 in. wide, made of clear white pine, smoothly planed. This trough is screwed fast to the center of the rear car. In the trough slides in either direction a wrought-iron weight 5 in. in diameter and 3 in. high, weighing 16¼

pounds. Crude as the device may appear, it has answered its purpose perfectly. Shocks in ordinary handling of trains with slack couplings over sags, hog backs and working in yards, will move the disk from 2 to 8 in.; 12 in. has been estimated as sufficient to be injurious to live stock and equipment. Repeated blows of 12 to 20 in.

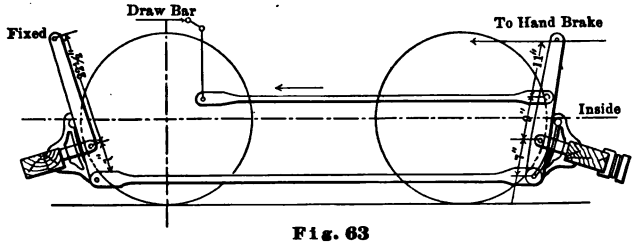


Fig. 63
American Buffer Brake, St. Louis & San Francisco Cars.

in the mixed and loaded car tests were sufficient to start the loads at the rear of the train through the ends of the cars; the loaded car thus, through the movement of their loads, becoming a check in weighing the length of the slideometer movement that was admissible and inadmissible.

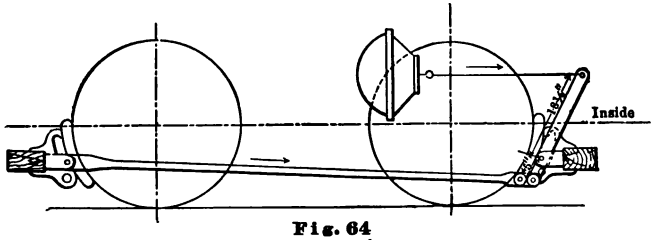


Fig. 64
Total Brake Leverage for { 1 Truck, 1 to 8.4 / 1 Car, 1 to 16.8
Eames Vacuum Brake, Indianapolis, Decatur & Springfield Cars.

Foundation Brake Gear.

In the application of brakes to equipment, one of the most important details is the foundation gear or parts that are common to both hand brakes and power brakes, and equally essential to the efficient working of the one as the other. But very little appreciation of the importance

of this was shown by railroads at that time, judging from the fact that thousands of freight cars of 40,000 pounds capacity and over were running, and being built with the old inefficient foundation gear, applied only to one truck. It might have been expected, however,

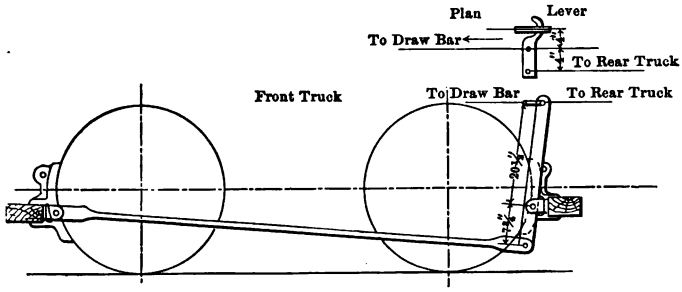


Fig. 65

Rote Buffer Brake, Chicago, Rock Island & Pacific Cars.

that the competitors in such an important series of tests as these would at least have seen that so vital a detail was arranged in such a way that would produce a proper equalization of power over the eight wheels of each car. Such was not the case. By referring to Figs. 63 to 67 of the

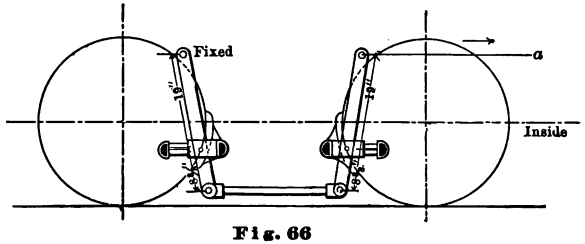


Fig. 66

Total Brake Leverage for one Car. 1 To 9.2

Westinghouse Automatic Air Brake, Chicago, Burlington & Quincy Cars.

brake-gear, it will be observed that two only of the five competitors of 1886 (Figs. 66 and 67) had the braking power properly equalized. Fig. 63 is equalized properly for hand brakes, but not for power brakes.

Air Brake Tests

THE BURLINGTON BRAKE TRIALS

We give on the next page a table taken from the *Railroad Gazette* of July 30, 1886, showing the comparative efficiency of the five competitors of 1886.

No attempt has been made to deduct these sources of error from the table of stops, though it is clear they should not be allowed to weigh in impairing the value of any power brake.

By reference to the table of stops it will be noted that no hand-brake stops were made with the Indianapolis, Decatur & Springfield train.

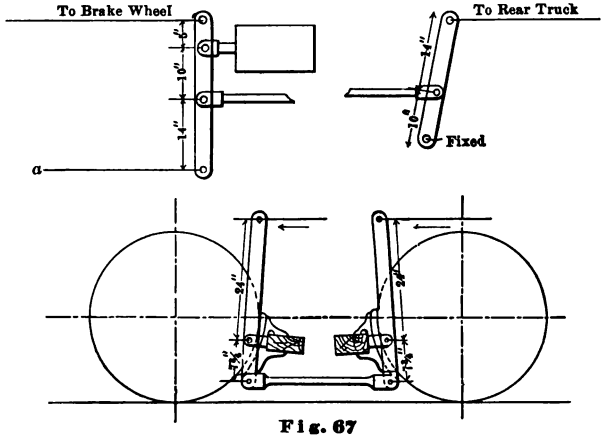


Fig. 67

Widdifield & Button Friction Buffer Brake, Lehigh Valley Cars.

This was owing to the fact that its hand-brake rigging was only connected to one truck. It would therefore have taken the brakemen twice as long to have applied the same number of brakes that they did with the trains of the other competitors, which had the brakes of both trucks connected.

Break-in-Two Tests — Special No. 1, 1886.

One of the most important features of continuous brakes is the control given trainmen of stopping the train at any point in case of emergency without communication with the engineer, which may be done by breaking a hose coupling or by opening stop-cock on the rear car.

TABLE XIII.

Table Showing Proportions and Comparative Efficiency of the Foundation Brake-Gear of the Five Competitors at the Burlington Brake Tests, as shown in Figs. 63 to 67.

Fig.	Brake Co.	Kind of Brake.	Road Owning Cars.	Pressure on Brake-Beams per 1,000 Lbs. Pull on Brake-Rod.		Comparative Efficiency.		Average effic'ncy per cent. of max.	Loss of effic'ncy per cent.	Approx. weight of cars.	Weight per axle empty.
				First axle.	Second axle.	First.	Second.				
				Lbs.	Lbs.						
63	American	Direct buffer . . .	St. L. & S. F.	2,286	1,686	100.	73.7	86.9	13.1	27,600	4,600
64	Eames	Automatic vacuum	I., D. & S. .	4,700	3,700	100.	78.7	89.4	10.6	21,000	3,500
65	Rote	Direct buffer . . .	C., R. I. & P.	3,645	2,645	100.	72.6	86.3	13.7	24,000	4,000
66	Westinghouse . .	Automatic air . .	C., B. & Q. .	3,235	3,235	100.	100.	100.	. .	24,100	4,016
67	Widdifield & Button	Friction buffer . .	L. V. . . .	3,097	3,097	100.	100.	100.	. .	21,000	3,500

The American brake cars were equalized for hand brakes, but not for power brakes, as will be seen from Fig. 63. Tension of 1,000 lbs. on hand-brake rod throws a pressure of 3,286 lbs. on the brake-beams. After the bad results of the first 50-car tests, the brake leverage was altered so as to bring the brake-beam 2 in. nearer the lower brake-rod, increasing the brake-beam pressure per 1,000 lbs. tension on draw-bar from 2,286 and 1,686 to 3,200 and 2,200. This had the effect of remedying the constant breakage of brake-beams, but rather increased than diminished the shock on the rear car.

The Westinghouse brake is provided with an 8-in. cylinder, and for a working pressure of 50 lbs. per sq. in., which is rarely exceeded, and throws a pressure of 5,807 lbs. on the brake-beams.

The Eames brake uses a diaphragm of 15 in. external diameter and 119 sq. in. effective area. The working vacuum of 15 to 20 in. gives a pull of only 893 to 1,190 lbs. on the brake-rod, or 4,195 to 5,593 lbs. on the first brake-beam, and only 78.7 per cent. of that on the other brake-beam.

This advantage will be more fully appreciated by those who have watched the frantic endeavors of brakemen on the top of a long train to signal a stop to the engineer who has started before all was ready in the rear. Similar experience came up every now and then during the tests, which at once resulted in the windmill arm motion of the brakemen crossways with the track. It was not long, however, before they discovered the power that was in their control in handling the Westinghouse and the Eames train, and the celerity with which they discarded the arm motion and opened the rear stop-cock or parted a hose-coupling was remarkable and fully equal to the passenger conductor's confident pull on the conductor's valve of the automatic air brake when he wishes to stop a train promptly. Special Test No. 1, or the break-in-two test, was intended especially to develop this feature of a freight train brake and was creditably performed by the Westinghouse and the Eames companies. The other competitors obviously from their construction were unable to participate in this competition:

Table XIV. on next page shows the result of the tests. The trains were parted between the thirteenth and fourteenth car, counting from the engine, the train being composed of 25 cars, mixed loads. In test 1451 of the Eames, owing to a misunderstanding of orders, the engineer was not allowed to work his ejector after the breakaway occurred, which resulted in the rear train running into the forward one with some force and damaging two of the cars. In the subsequent tests, by working the ejector, the brakes were kept off the forward train until all danger of collision was passed.

Down-grade Run — General Test No. 3.

One of the severest tests, and the one most dreaded by the competitors' engineers, was the down-grade run described in the competition as No. 3 of the general tests. The train was composed of 50 cars, half loaded and half empty cars, and in addition the dynamometer and way car. The ground selected for the run was the stretch of track between stop No. 3 and the distance post covering 2.021 miles. The speed passing stop-post No. 3 was to be 20 miles per hour, and re-

TABLE XIV.

Stop Number.	Name of Brake.	Train.	Trainpipe Pressure. Engine.	Trainpipe Pressure. Rear Car.	Speed in Miles at Parting of Train.	Distance Between Sections During and at Stop.	Movement of Slideometer, Rear Car, in inches.	Miscellaneous.
			Lbs.	Lbs.				
1411	Westinghouse	25 mixed cars, engine, dynamometer and way car	69	66	24	55 feet at stop	0	Train was separated by pulling the pin between the 13th and 14th car. A rope was suspended from top of car and attached to coupling pin.
1421	do.	25 mixed cars, engine, dynamometer and way car	67	64	41	Cars separated one car-length, came together and separated again 5 feet at stop	$1\frac{5}{16}$	
1431	do.	25 mixed cars, engine, dynamometer and way car	66	65	25	35 feet at stop	0	
1432	do.	25 mixed cars, engine, dynamometer and way car	67	65	$37\frac{1}{2}$	Sections came together with some force and remained until stop . . .	$\frac{1}{64}$	
1451	Eames . . .	23 mixed cars, engine, dynamometer and way car	$6\frac{1}{4}$	6	$22\frac{1}{2}$	Sections separated $1\frac{1}{2}$ car-lengths, then came together with considerable force and remained together . .	$16\frac{1}{4}$	2 cars damaged and set out at Middletown on return from stop.
1461	do. . . .	23 mixed cars, engine, dynamometer and way car	$7\frac{1}{4}$	$6\frac{1}{2}$	36	423 feet at stop	0	In the three last stops engineer worked the ejector on engine, thereby keeping the brakes off on front end until there was no danger of colliding.
1471	do. . . .	23 mixed cars, engine, dynamometer and way car	$7\frac{1}{4}$	$6\frac{1}{2}$	$25\frac{1}{2}$	150 feet at stop	0	
1472	do. . . .	23 mixed cars, engine, dynamometer and way car	$8\frac{1}{8}$	8	$26\frac{1}{2}$	25 feet at stop	0	

THE BURLINGTON BRAKE TRIALS

duced as soon as practicable to 15 miles, which was to be maintained uniformly during the remainder of the run. The general result of these runs can be best obtained from the speed record diagrams, which are shown in reduced scale by Figs. 68, 69, and 70.

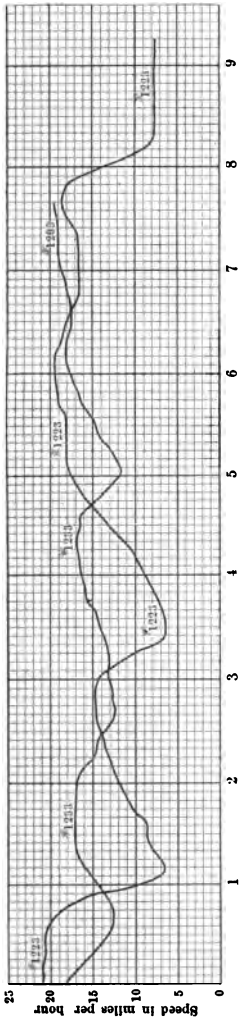


Fig. 68

The horizontal lines show the speed in miles per hour, while the vertical lines show the time at 5-second intervals. The figures show the time in minutes. Allowing 30 seconds to reduce the speed to 15 miles an hour, the run should have occupied about 7½ minutes. The diagrams showed very plainly great room for improvement in both the Eames and the Westinghouse brake, and were it not for the low speed would apparently have given the award to the American Brake Company, for up to 9 minutes it will be observed the speed was uniformly maintained between 8 and 10 miles per hour. This record, however, it should be borne in mind, was taken in the autographic car placed in the middle of the train. While the persons riding in this car and the dynamometer car were commenting on the uniformity of the run that was being made, although somewhat below the 15-mile speed, an entirely different record was being registered in the rear or 52d car. Here shock after shock was being received, their rapid succession adding to their intensity. Twenty-eight blows of more or less severity were given during

the run of 11½ minutes, culminating in a shock of 63 in., which broke the train in two. An examination of the train after the stop revealed the fact that 9 of the rear cars had their ends broken and bulged out by the shifting of the loads to such an extent that they were in a dangerous condition, and this, notwithstanding the fact that the wheels with which the cars were loaded had been stowed with special care and the ends of the car blocked with timber. This test was more instructive than any other could possibly have been, in showing the inherent weakness of brakes actuated by independent pulsations or blows transmitted through the draft springs. The record is all the more prominent as, notwithstanding the shock-producing powers developed by the continuous brakes in 50-car train stops, their down-grade runs were comparatively free from shocks :—

Eames test No. 1223—1 bump, $2\frac{7}{16}''$.
do. No. 1233—0 bumps.
Westinghouse test No. 1243—Bumps $\frac{1}{8}$, $3\frac{3}{16}$, $\frac{1}{2}$, $1\frac{1}{4}$, $\frac{7}{16}$, $\frac{1}{8}$, $\frac{1}{16}$.
do. do. 1253— do. $\frac{1}{8}$, $\frac{1}{16}$, $\frac{3}{16}$.
do. do. 1263— do. $\frac{1}{8}$, $\frac{5}{16}$.

The following are some of the shocks during the American's memorable run :

1st bump—$17\frac{1}{4}''$.
9th do. —$18\frac{1}{2}''$.
13th do. —$21\frac{3}{8}''$.
18th do. —$23\frac{3}{4}''$.
27th do. —$63''$.
Total number of blows, 28.

Dynamometer Car Diagrams.

We give (Plate V.) a few of the dynamometer-car diagrams of the 50-car trains, at stop two, which appeared in the *Railroad Gazette* of October 4, 1886. They are thus described :

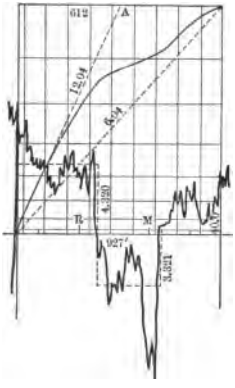
Each of the diagrams given consists of two parts :

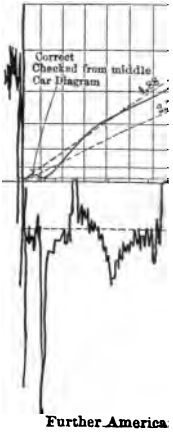
1. A direct photographic reproduction of the original record diagram taken in the dynamometer car.

Plate V

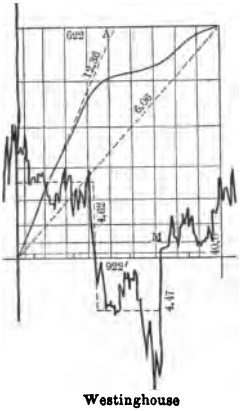
50 Empty Ca

Emergency Stops.

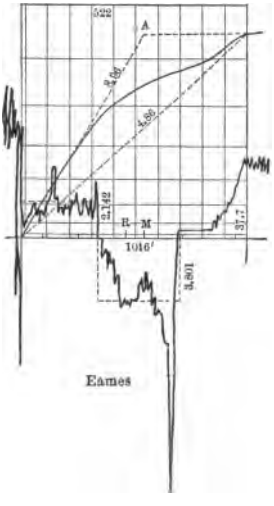




Further America



Westinghouse



Eames

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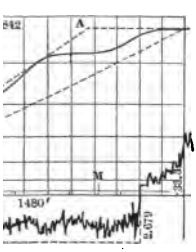
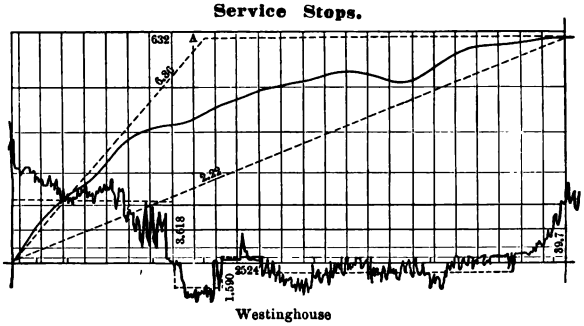
- CAR DIAGRAMS

I—General Tests.

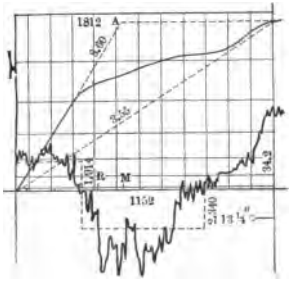
Service Stops.





Westinghouse

Tests Abandoned



ican

Eames

Air Brake Tests

THE BURLINGTON BRAKE TRIALS

2. A constructed diagram, drawn on the original sheets above the original machine record from data furnished by it, to represent the efficiency of the brakes during the stop or the rate at which the energy of motion was destroyed. This also is in effect an original record, since it follows it precisely, but it is reconstructed in a different and clearer form.

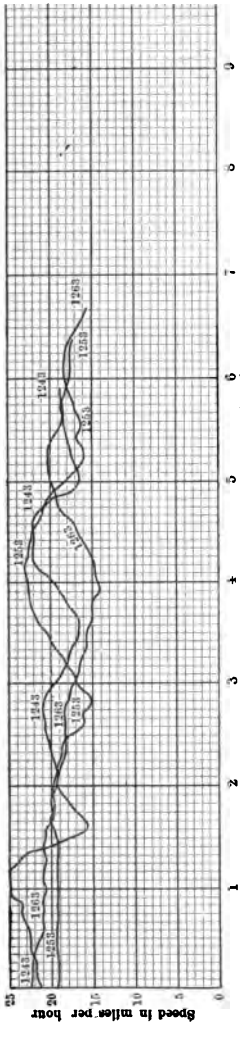


Fig. 69

The lines on the diagrams which belong to the first class (original records) are these:

(A.) The base or zero line, drawn on the diagram paper, as it is drawn slowly forward by the machinery by a separate pencil.

(B.) The irregular line drawn by the pencil connected with the dynamometer spring, which indicates the tension or compression acting in the draw-bar between the tender and first car. If the line is above the zero base line it indicates tension, or that the engine was pulling the train; if below it, compression, or that the train was pushing on the engine and tender brakes.

(C.) The time or speed record, given by electrically recorded dots at 5 seconds interval along a separate line, which have been transferred for engraving to the base line, and will be seen drawn upon it. (Some few have been lost in engraving.)

(D.) The beginning and end of every

stop, as electrically signaled from the engine. This also was recorded on a separate line, but for constructing the diagrams was indicated by *long vertical lines at the beginning and end of each stop.*

(E.) The time of application of the brakes on the *middle* car was accurately recorded by an apparatus on that car, and has been transferred to these diagrams by a mark shown thus—*M*—along the base line. The time in seconds from the signal to the *rear* car that brakes had been applied on the engine to the time when the brake was seen to go on the rear car was also noted and the record transferred to these diagrams marked thus—*R*. In many of these stops these records were imperfect or not taken at all, so that they do not always appear.

(F.) The distance run is an actual measurement from a row of stakes, merely checked (and some few important errors discovered) by the diagram records.

(G.) In the 50-car mixed and loaded tests it will be seen that there is a long stretch before the stop proper began (500 ft. in the 20 miles per hour stops; 1,000 ft. in the 40 miles per hour stops) where steam was shut off. This was done to reduce as much as possible the severe shocks resulting from the application of the brakes by letting the train close up somewhat before the brakes were applied. The speed of the train fell, of course, after the steam was shut off, but the speed was taken at whatever it was in passing the stop-post.

(H.) This initial speed is shown in figures, in miles per hour, on the vertical line at the beginning of each stop, just above the base line.

(I.) The movements of the impact gauge in inches are shown by small circles at the end of horizontal lines, starting from the first vertical as a base. The length of the horizontal line is proportional to the movement of the gauge, and the latter is also given in figures. Where there was only one shock, there is only one of these lines; where there were several there is a line for each. When there was a shock too slight to move the impact gauge the small circle is put directly on the base line.

The impact gauge was not thought of nor invented until the ninth

morning of the tests, after most of the 25-car tests and some of the 50-car tests had been made. Consequently only a portion of the diagram show this record.

The diagrams of the No. 3 and No. 4 stops, made on the down grade, were similar in all essential respects to the No. 1 and No. 2 stops, which have been engraved, except that they were longer because of the down grade. The buffer brakes make a somewhat poorer relative showing on these down-grade stops, as is natural from the fact that they depend on the force with which the engine crowds back against the train, which is reduced on down grades, but it does not appear necessary to engrave them also, as all necessary details of the action of the brakes are shown in the diagrams engraved.

Those are the autographic records, and before explaining the constructed diagrams, which are the most conspicuous feature on the sheet, we may explain some features of the dynamometer record.

The stop begins in all cases at the right of the diagram. The engine was then always pulling with more or less force; with how much may be read from the diagrams by a vertical scale of 23,400 lbs., or 11.7 tons, per inch (on the original 6,000 lbs. per inch). On the signal to apply brakes the throttle was instantly closed, and we should expect, therefore, that the traction would instantly fall to

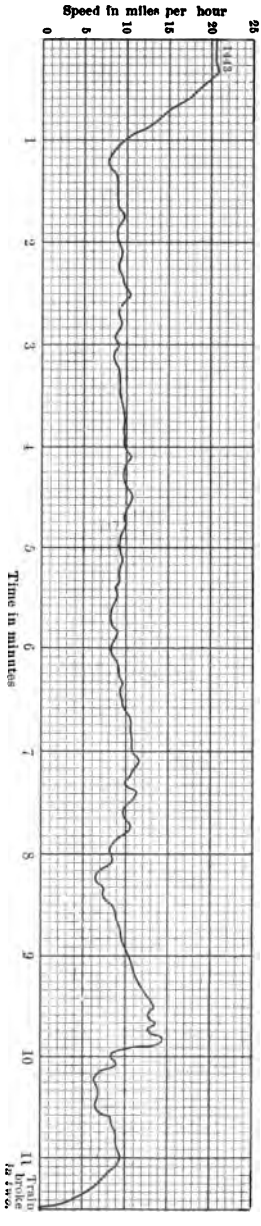


Fig. 70

American

zero, but it will be seen that this was never the case. By the combined effect of the steam left between the throttle and the piston, the evaporation of any entrained water in the steam chest and pipes, the re-evaporation of any condensed steam in the cylinders (all this steam, of course, being more or less superheated as the pressure fell, and expanded as long as there was any left to expand), a very considerable amount of work was done by the engine (three different ones were used) for several strokes after steam was shut off, with an economy of steam, no doubt, which would make any road the envy of its neighbors, if it could be habitually realized. It was made entirely certain that the throttles did not leak appreciably, yet it will be seen that this effect was invariably apparent for from 50 to 200 ft. after steam was shut off, despite the action of the driver brakes to counteract it.

The engine machinery having been once brought to a state of equilibrium, however, it will be apparent that, whatever the absolute efficiency of the brakes as a whole, if the engine brakes were retarding the engine, and the train brakes retarding the train, *at the same rate*, there would be neither push nor pull on the dynamometer draw-bar, but the traction line would fall down to the zero base line and remain on it during the stop. In no case did this occur, even approximately.

If, on the other hand, the engine brakes are acting decidedly more efficiently than the train brakes, the engine will push back against the train, and the traction line, which in the beginning indicated tension, will fall below the zero line, indicating compression. In every one of the diagrams this takes place, and in most of them, after an inexplicably long interval of 5 to 10 or more seconds, the driver brakes took hold with intense vigor, long before the train brakes began to act effectually.

If, then, later in the stop, the car brakes "get a good hold" or the driver brakes weaken, or both, the train will pull back on the engine and the traction line go back to tension, or above the base line. This occured in all the Westinghouse and in many of the Eames stops.

The buffer brakes, since they derived their power from compression of the draw-bars, necessarily must have had the engine holding back against

THE BURLINGTON BRAKE TRIALS

the train (in other words, have had the car brakes less efficient than the engine brakes) or they would not act at all. Hence, after the brakes began to act, they all showed considerable and continuous compression.

The average compression or tension during the stop, or various parts thereof, was accurately determined by planimeter measurements in the usual way, and is recorded in tons (2,000 lbs.) of compression (or tension) on the diagrams.

We come now to the constructed efficiency diagram, shown in the network of squares just above the traction record, and drawn on the same zero line as a base line.

The precise nature of this diagram we can best explain in this way: Turn the sheet upside down. The solid line running across each diagram is now *the profile of an up-grade* which would have brought the train to a stop, or down to any given speed, in precisely the same distance and in the same time and the same way as the brakes actually did.

If the action of the brakes had been precisely uniform from beginning to end of the stop, a grade to imitate its effect should be a straight grade, like those shown by the long, straight dotted line across each diagram. If the brakes took hold badly at first, and better and better toward the end, as in most cases they did, a grade to imitate their effect should be an easy one at first, and grow steeper and steeper toward the end, as is the case with most of them. If the action of the brakes was irregular, taking hold and then letting go somewhat, the "grade" should also be irregular, as it is in some of them.

If we wish to determine what length the stop would have to be, had the brakes been as efficient throughout as they were during the latter end of the stop, we have only to prolong the final "grade" down (or up) to the point A, where we strike the level at which our "grade" starts. This has been done on every one of these diagrams, and the rates in per cent. (1 per cent.=52.8 ft. per mile) are shown, first for an average grade, which would have stopped the train in the same distance, but not in just the same way as the brakes did, and, secondly, of

the grade corresponding to the efficiency of the brakes towards the end of the stop. These percentages also show the retarding effect of the brakes in lbs. per 100 lbs. of *total* weight of train. The more satisfactory basis of comparison, however, is in lbs. per 100 lbs. of load *on braked wheels*, which will appear in the tabular records.

The vertical lines of the diagram show distances of 100 ft., starting from the beginning of the stop, and hence leaving a fractional distance at the end. The horizontal lines are for speeds of 5, 10, 15, 20, and 25 miles per hour. They are not spaced equally, however, but according to the *energy* represented by that velocity. A train moving at 20 miles per hour has four times as much stored energy or momentum to be destroyed by the brakes as one moving at 10 miles per hour, and that again as one moving at 5 miles per hour. Consequently, the 5-mile line is very close to the zero base line, and the others are at increasing intervals apart.

The diagram was constructed thus: The dynamometer paper being moved at 2 ft. per mile, and check-marks being electrically recorded on it at 5-second intervals, a scale of 30 parts per inch reads off the speed in miles per hour during that 5 seconds. When the speed is decreasing during a stop these marks come closer and closer together on the paper. The space between each was read, a perpendicular erected in the middle of each space, and the energy corresponding to that speed in vertical feet of potential lift laid off by a uniform arbitrary scale. The efficiency line was then passed through these points without correction. In a few cases where corrections seemed needed they have been indicated by a dotted line, but the full line is the actual uncorrected record.

Some irregularities of the diagram are due to the effect of slack. There being several feet of slack in the train, and the record being that of the front car, a sudden increase of driver-brake efficiency could check back the front cars and cause a great apparent retardation, which would be lost in the next 5 seconds by the whole train crowding upon it when the slack came all out.

Air Brake Tests

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General Tests.

At the beginning of the trials your Committee viewed, with some dismay, from the number of competitors with trains, the long series of tests each expected to go through and the prolonged work that would necessarily follow. At an early day, however, it became evident that few, if any, of those who had participated in the joint meetings at which the tests were framed, realized the perfection the brake problem must attain before any competitor could successfully go through a programme such as had been mapped out. The result was a gradual dropping out of the weaker contestants, as they were called upon to perform the more severe competitions. These failures materially shortened the contest.

The Rote Brake Company, in some preliminary work before the trials commenced, developed such complete lack of braking power that an extension of time was asked in which to remodel the mechanism. This was readily granted. On the 17th and 18th days, towards the end of the contest, one run each was made over the course with a 25 mixed car train, emergency stops. The complete failure of the brake in making any record is shown in tables series B and C of 1886, plates III. and IV., stop numbers 1751 to 1754, and 1831 to 1834. The Widdifield & Button friction buffer brake early in the contest developed an entirely unlooked for feature, in making its quick stop record, which, perhaps, surprised no one more than it did the inventor of the brake. In making stops with 25-car trains, and brakes on all cars, a succession of violent shocks was produced in the rear. The brakes were very sensitive, and the very fact of the retardation due to their going on also served to pull them off; the released cars, as soon as they exhausted their slack, buffed against the engine, which action at once reapplied the brakes, to be almost as quickly released again, and so on in alternate succession until the final stop was made. A readjustment of the brake was asked for and allowed, which decreased the number of shocks in the rear, but at a sacrifice in the length of stop. The succession of shocks, however, though in a diminished form, was still so apparent that it was not considered prudent to attempt any stop with brakes on 50 cars, and

the Widdifield & Button stops were in consequence confined to runs with trains having automatic brakes on 25 and 30 cars only. Unfortunately there is no slideometer record of these earlier tests; the necessity for such a device did not force itself on those in charge of the contest until the ninth day.

The American Brake Company entered the trials in a very unprepared condition, and consequently under decided disadvantages. A few weeks prior to the contest their equipment, which had just been built and was ready for preparatory work, was completely destroyed by a fire at the shops of the builders. A new lot of cars was at once ordered, but not completed until after the contest had commenced. The American Company, therefore, was obliged to enter with practically an unproved train. They, nevertheless, pluckily took their place in the contest, and after some adjustment succeeded in making a fair record in the trains with 25 cars braked, as will be seen by the figures in plate III. They then entered the 50 empty car train, all cars braked, making one service and one emergency run over the course. Here it was clear the limit was reached. The additional cars develop the violent successive shocks of the Widdifield & Button train to such an extent that it was not deemed safe to make any stops with the 50 mixed or loaded trains, all cars braked. The down-grade run, however, with the 50 mixed car train was tried, which, while unfortunate for the brake company, shed a flood of light on the action of independent brakes that will be invaluable to railroad companies for years to come.

Thus towards the close of the contest the only surviving competitors were the Eames and the Westinghouse, and even with these, such violent shocks were given in stops with all 50 cars braked that the Committee was obliged to amend its rules, and convert the 50 mixed and loaded car stops into service stops; that is to say, stops that an engineer would make in the ordinary handling of his train with a view to avoid any damage in the rear, rather than to make his shortest possible stop. It will be noted, therefore, in plate III., that in these stops the engineers were allowed to shut off steam 500 feet and 1,000

THE BURLINGTON BRAKE TRIALS

feet before reaching the stop-post, and thus bunch the train before the stop signal was given, and even then gradual application was made in place of emergency. Had these precautions not been taken, a continuance of the shocks not only would have been exceedingly dangerous to those riding on the train but would soon have rendered all cars unfit for service. The explanation of the violence of the shock with the continuous brakes clearly is the same as in the independent brakes, viz., successive application from the engine. The intervals in 25 and shorter car trains had not been sufficient to fully bring this out. It was only when the jump was made to a 50-car train, together with the natural desire of each competitor for a record of the shortest stop, that successive application assumed the shape of impracticability. This readily accounts for the 50-car trains, with only automatic brakes on the forward 29½ cars, in the shorter stops so closely equaling (in some cases surpassing) the emergency stops with brakes on the 50 cars.

TABLE XV.

Kind of stop.	Name.	No. of Stops.	Cars braked and unbraked.	Weight, including engine and all cars.	Length of stop corrected to 20 miles an hour.
50-car train, engine and 29½ car brakes	Westinghouse	1,631	51	1,380,102	313
do. do. and all car brakes .	do.	621	52	1,404,190	307
do. do. do. .	do.	611	52	1,404,190	340
do. do. and 29½ car brakes	Eames . . .	1,821	52	1,246,050	345
do. do. and all car brakes .	do. . . .	521	51	1,383,897	348
do. do. do. .	do. . . .	511	51	1,383,897	383
do. do. and 29½ car brakes	American .	1,321	50	1,521,094	396
do. do. and all car brakes .	do. .	831	52	1,576,260	392

At stops 2, 3, and 4, where longer time was occupied in the stops, more brakes went on, and consequently shortened the stops to some extent. Perhaps a still better appreciation of this slowness of application may be had from an examination of the brake-beam stress diagrams. It will be observed from the reading of the diagram that in Westing-

house stop No. 1611, Fig. 98, page 228, a close-coupled 50 empty car train, speed 22 miles, distance 418 feet (corrected to 20 miles, 345 feet), no force whatever was exerted against the wheels of the 25th car until nearly 13 seconds out of a total of 18 had elapsed and 364 feet of the stop had been made. In a corresponding Eames stop, No. 521, Fig. 96, page 226, speed 22.4 miles, distance 437 feet (corrected to 20 miles, 348 feet), the first application is comparatively much better, viz.: 8 seconds out of a total of 19, and, at a travel of 250 feet, this great advantage, unfortunately for the Eames company, is completely lost by the exceedingly slow development of power, which is well brought out by these middle-car diagrams. A glance down plates VIII. and IX. at the 1887 diagrams will show how fully the competitors realized the imperfections in their 1886 mechanism.

Slack and Close Coupled Train.

As pertaining to the question of shock in successive application of brakes, it was apparent the amount of slack in each train would have considerable influence in increasing the violence of any shock. The Committee determined to ascertain to what extent this influence might be reduced, by eliminating as much of the loose slack as was practicable. We quote the test as reported in the *Railroad Gazette* of August 6, 1886.

"The Westinghouse train of Burlington & Quincy cars, from which the severest shocks have been received and which likewise had the most slack, was selected for the test. For the test a lot of 3 in. scrap arch-bars were cut up into pieces about 12 in. long, punched and riveted together near the centers, making a very snug fit in the links. No trouble was experienced from their jumping out, and they took out 3 in. of 3½ full slack. The result was certainly very decisive and convincing.

"The train was made up of 49 empty cars, or within one of the same number as had been used in the earlier empty cars emergency runs. While the stops were on an average quite as good as the previous

emergency stops, the shocks were of the following mild and gentle description:

"Test No. 1600, Westinghouse, 49 empty car train, emergency stops, close couplings—

	Speed.	Distance.	Time.	Impact Gauge.
Stop No. 1611 . . .	22	418 feet.	18 seconds.	$18\frac{7}{16}$ inches.
do. 1612 . . .	$39\frac{1}{2}$	959 do.	$23\frac{1}{2}$ do.	$15\frac{3}{4}$ do.
do. 1613 . . .	26	513 do.	$17\frac{1}{2}$ do.	$19\frac{3}{8}$ do.
do. 1614 . . .	43	1,106 do.	25 do.	$21\frac{5}{8}$ do.

"A 20-inch bump will throw a car-load of stock toward one end of the car in very energetic fashion, but is a very different affair from a 120-in. bump, at which figure the Westinghouse loose-coupling shocks were estimated.

"The amount of slack in the Chicago, Burlington & Quincy cars may be estimated for each train about as follows:

	Loose slack.
In link	$3\frac{1}{2}$ in.
From bending of pins and occasional slack springs in draw-bars	$\frac{1}{2}$ in.
In springs, $2\frac{1}{4}$ in., total motion in 15,000-lb. springs, all of which (and considerably more, if there were more) is, beyond question, used up in every shock, but with a diminution of the force of the blow, so that the $4\frac{1}{2}$ in. of spring slack may be estimated as the equivalent in free slack of	$2\frac{1}{2}$ in.
Total free slack or equivalent	$6\frac{1}{2}$ in.
Of which there was taken up by the blocks	3 in.
Leaving in close coupled train, per car . . .	$3\frac{1}{2}$ in.

Or nearly as may be half as much free slack, with the result that, with a 50 empty car train:

$6\frac{1}{2}$ in. of free slack, 27 ft. in the train, give an impact at the rear of (estimated) . . . . . 120 in.

$3\frac{1}{2}$ in. of free slack, $14\frac{1}{2}$ ft. in the train, give an impact in the rear of . . . . . 20 in."

A more convincing demonstration that slack added to the intensity of shocks in trains making stops or in passing over hog-backs and dips of undulating road-beds could hardly be made.

Conclusions.

The results of these 1886 tests were disappointing. None of the competitors did satisfactory work, owing to the violent shocks produced in stopping. Slack in long trains controlled with power brakes, applied successively from the engine, assumed at once a most prominent part in this and doubtless all future contests. The expected delays in charging and releasing continuous brakes was shown to be of no moment, and while the objections of successive application was developed to an extent calling for the most serious consideration, there clearly was a future for continuous brakes in more instantaneous application which their independent competitors could never hope for. Few now will be found spending their energies on the Buffer type of brake. No clearer evidence of its impracticability can be given than the fact that successive application is one of its indispensable features, and the gradual withdrawal of this type of brake from the attention of the railroads in this country dated from the Master Car Builders' contest of 1886.

Abandonment of Endurance Test.

The Committee's work as laid out had in contemplation an endurance test of nine months' regular service. The contest, however, had developed so many points where improvements might be made, that at a meeting held in New York in the month of September, following the 1886 contest, it was decided to abandon the endurance test and its restrictions.

GENERAL TESTS, MAY, 1887.

(1.) 50 empty car train over the course prescribed, making four emergency stops:

No. 1 stop, on level, 20 miles per hour.

No. 2 stop, on level, 40 miles per hour.

No. 3 stop, 53 ft. grade, 20 miles per hour.

No. 4 stop, 53 ft. grade, 40 miles per hour.

(2.) 50 mixed car train, ⅔ of the cars to be loaded to their full capacity, and ⅓ to be empty; 75 per cent. of the latter to be in the front half of the train; four emergency stops:

No. 1 stop, on level, 20 miles per hour.

No. 2 stop, on level, 30 miles per hour.

No. 3 stop, 53 ft. grade, 20 miles per hour.

No. 4 stop, 53 ft. grade, 30 miles per hour.

(3.) 50 mixed car train, with hand brakes and engine, and tender automatic brakes; four emergency stops:

No. 1 stop, on level, 20 miles per hour.

No. 2 stop, on level, 30 miles per hour.

No. 3 stop, 53 ft. grade, 20 miles per hour.

No. 4 stop, 53 ft. grade, 30 miles per hour.

(4.) The 50 mixed car train to be let down a grade of 53 feet per mile, 3 miles long. Speed of 20 miles per hour at the top of the grade, to be reduced to 15 miles per hour as soon as practicable, and maintained without material variation all the way down the grade.

(5.) 50 mixed car train once over the course. Brake shoes to have a slack of from ½ inch to ¾ inch each; four emergency stops:

No. 1, on level, 20 miles per hour.

No. 2, on level, 30 miles per hours.

No. 3, 53 ft. grade, 20 miles per hour.

No. 4, 53 ft. grade, 30 miles per hour.

(6.) 50 empty car train, engines brakes only to be used; 1 stop, on level, 20 miles per hour.

(7.) Engine tests; engine and dynamometer car; 2 stops on level

track at 20 and 40 miles per hour, and 2 stops on 53 ft. grade at 20 and 40 miles per hour.

(8.) 50 empty car train, hand brake stop, with engine and tender automatic brakes; once over the course prescribed, making 4 emergency stops:

No. 1 stop, on level, 20 miles per hour.

No. 2 stop, on level, 40 miles per hour.

No. 3 stop, 53 ft. grade, 20 miles per hour.

No. 4 stop, 53 ft. grade, 40 miles per hour.

Special Tests.

(9.) 50 mixed car train; tests to be made on level. Trains to be broken in two or more unequal parts. After trains are broken any assistance necessary shall be rendered by the brakeman, who will be riding on the rear of the train or on the engine when the breakaway occurs:

No. 1 breakaway, on level, 20 miles per hour.

No. 2 breakaway, on level, 30 miles per hour.

(10.) 50 empty car train; train resistance test:

No. 1. To pass No. 1 stop-post at 20 miles per hour, letting the train drift till it stops, no brakes being applied.

No. 2. To pass No. 3 stop-post at 5 miles per hour, letting the train drift until No. 4 post is reached, at which point the accelerated speed shall be recorded and the train stopped.

The same arrangement of dynamometer-car and middle-car recording apparatus to be used as in the first trials.

May, 1887, Brake Tests.

The May, 1887, tests were made over the same course as in 1886, and with practically the same recording apparatus and detailed rules, with a few modifications suggested by the tests of last year. The Committee were again indebted to the following corps of assistants, and the railroad companies they represented, for valuable aid during the contest:

Assistants on Engine — R. W. Bailey, Assistant Engineer of Tests,

THE BURLINGTON BRAKE TRIALS

P., C. & St. L. R'y Co.; S. P. Bush, Mechanical Engineer's office, P., C. & St. L. R'y Co.; W. C. Squire, Test Department, C., B. & Q. R. R. Co.

ASSISTANTS IN DYNAMOMETER CAR — F. W. Sargent, Engineer of Tests, C., B. & Q. R. R. Co.; W. W. Nichols, Assistant Engineer of Tests, C. B. & Q. R. R. Co.; E. P. Lord, Penn. R. R. Co.

ASSISTANTS IN MIDDLE CAR—Wm. Forsyth, Mechanical Engineer, C., B. & Q. R. R. Co.; H. Guels, Mechanical Engineer, American Brake Co.; W. H. Peirce, Mechanical Engineer's office, C., B. & Q. R. R. Co.

ASSISTANTS IN WAY CAR — R. Ryan, Mechanical Engineer's office, C., B. & Q. R. R. Co.; E. W. Penfield, Test Department, C., B. & Q. R. R. Co.; A. H. Bowman, Electrician, Lehigh Valley R. R. Co.; W. Nettleton, Superintendent of Brakes, Kansas City, Fort Scott & Gulf R. R. Co.

At the May, 1887, tests five companies were represented.

The Westinghouse Air Brake, Pittsburg, Pennsylvania.

The Eames Vacuum, Boston, Massachusetts.

The Hanscom Air Brake, San Francisco, California.

The Carpenter Automatic Electro Air Brake, 15 Gold Street, New York, N. Y.

The Card Electric Brake, Cincinnati, Ohio.

It will be observed that only the continuous type of brake entered this year's contest. The 1886 tests had shown clearly that quick application on long trains was the only method of avoiding the shock at the rear of the train. Special attention had been given this by the competitors; even the Westinghouse and the Eames companies coming in 1887 with electric appliances adapted to their brakes, through which they could obtain instantaneous application. It is a well-recognized fact that there is no mechanical difficulty in getting any amount of braking power on a car; the difficulty has been in getting a quick application.

Westinghouse Brake.

The Westinghouse Company used 50 Pennsylvania Railroad standard 60,000-lb. cars, the average weight being 30,577 lbs., and fitted with

the Janney coupler. The brakes were fitted this year with the quick-action triple valve. The first sharp reduction of air put the triple valve nearest the engine into action, and the air it drew from the trainpipe started the next triple, and so on throughout the entire train.

Figs. 71, 72, and 73 represent sections and plan of this triple valve; Fig. 72 is a different section of the lower part of Fig. 71. In working the ordinary triple valve of the Westinghouse automatic air brake, air passed in through the trainpipe by the openings *a*, *b*, *c*, Fig. 71, into the drain-cup A, from whence it went up through holes *r*, Fig. 72, into the chamber B, Fig. 71, pushed up the piston 5 and the slide valve 6 connected with the piston. This was the normal position of the apparatus when the train was running. The piston and slide valve attached being up, the brake-cylinder was open to the atmosphere by means of the passages and ports *d*, *e*, *f*, *p*, *q*. To apply the brake, air was permitted to escape from the trainpipe, which reduced the pressure at B, when the higher pressure in the auxiliary reservoir pushed down the piston 5, carrying with it the slide valve 6, thereby putting the auxiliary reservoir, by means of the port *l*, open to the brake cylinder. The degree of opening, and hence the quickness of application, was in direct proportion to the reduction of pressure made in the trainpipe.

The new triple valve worked precisely the same way as the old one when a light reduction of air was made in the trainpipe. But when a quick stop was wanted sufficient air was exhausted at first to make piston 5 push down valve 15 far enough to open the port *s*, Fig. 72, when the air from the trainpipe rushed up through a suitable passage *x*, Figs. 72 and 73, into the brake-cylinder. When the air in the brake-cylinder and in the trainpipe came to have the same pressure, the valve 16 closed automatically, and prevented the air from the auxiliary reservoir from passing into the trainpipe. At the instant the descent of the piston 5 moved the valve 15 and opened the port *s* for the air in the trainpipe to pass into the brake-cylinder, the port *m* on the slide valve 6, put the auxiliary reservoir in communication with the brake-cylinder also. When the engineer made the reduction of pressure necessary to start

THE BURLINGTON BRAKE TRIALS

the operation which let the air from the trainpipe pass into the brake-cylinder, he immediately put the handle of his valve on lap, to prevent the passage of air from the main reservoir into the trainpipe. By the new arrangements the greater portion of the air in the trainpipe was utilized to operate the brake, by flowing into the brake-cylinder, instead of being exhausted into the atmosphere. The first sharp reduction of air put the triple valve nearest the engine into action, and the air it drew from the trainpipe started the next triple, and so on it went throughout a train of 50 cars or more. Application to the whole train of 50 cars was made in about 6 seconds, compared with 17 seconds required with the common triple.

The electrical device used is explained in the sub-committee's report. It consisted of a valve which, by the passage of an electric current, let the air in the trainpipe escape into the atmosphere. It was not intended to use this valve on every car, but in some three or four points on a long train. Its practical effect was, instead of allowing the air to escape from the trainpipe only at the engineer's valve, it escaped at four points on the train.

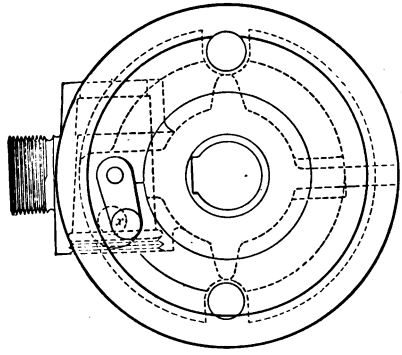
Eames Vacuum Brake.

The Eames Vacuum Brake Company had 50 cars of 40,000 lbs. capacity built to the Chicago, Burlington & Quincy standard for the brake company in Chicago. They had also undergone important changes during the past year, which have greatly increased the brake's efficiency. The diaphragms and auxiliary reservoirs had been enlarged. The main improvements, however, were in the ejector, the valve, its electric attachment, and the leverage. The leverage was arranged with a floating fulcrum, the effect of which was to increase the power with the travel of the diaphragm. The brake shoes being hung from the car body, their distance from the wheels, and consequently the stroke of the diaphragm, was increased when the car was loaded, and the effect of the floating fulcrum was to increase the leverage when the car was loaded.

The description of the Eames automatic brakes as used in 1886 applies to that used in 1887, with the following improvements:

1st. An electrical attachment, Fig. 74, which would apply, release

Fig. 73



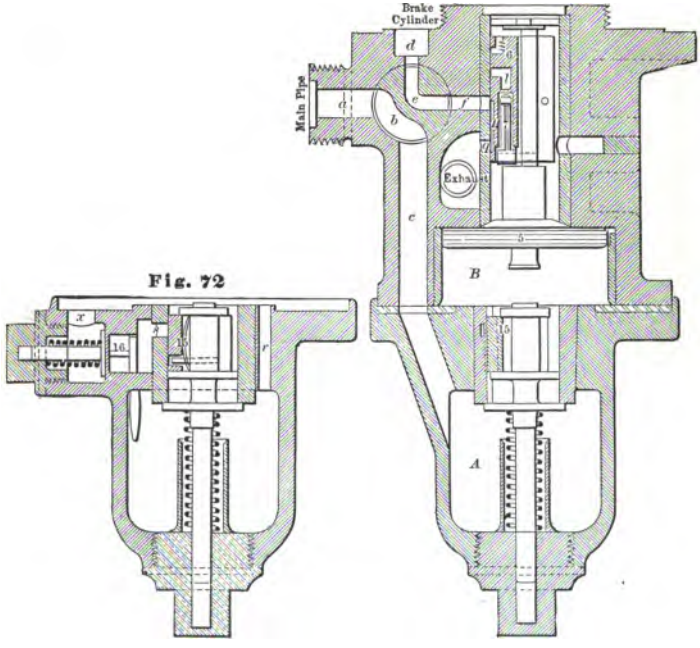


Fig. 72

Fig. 71

Westinghouse Quick-Action Triple Valve.

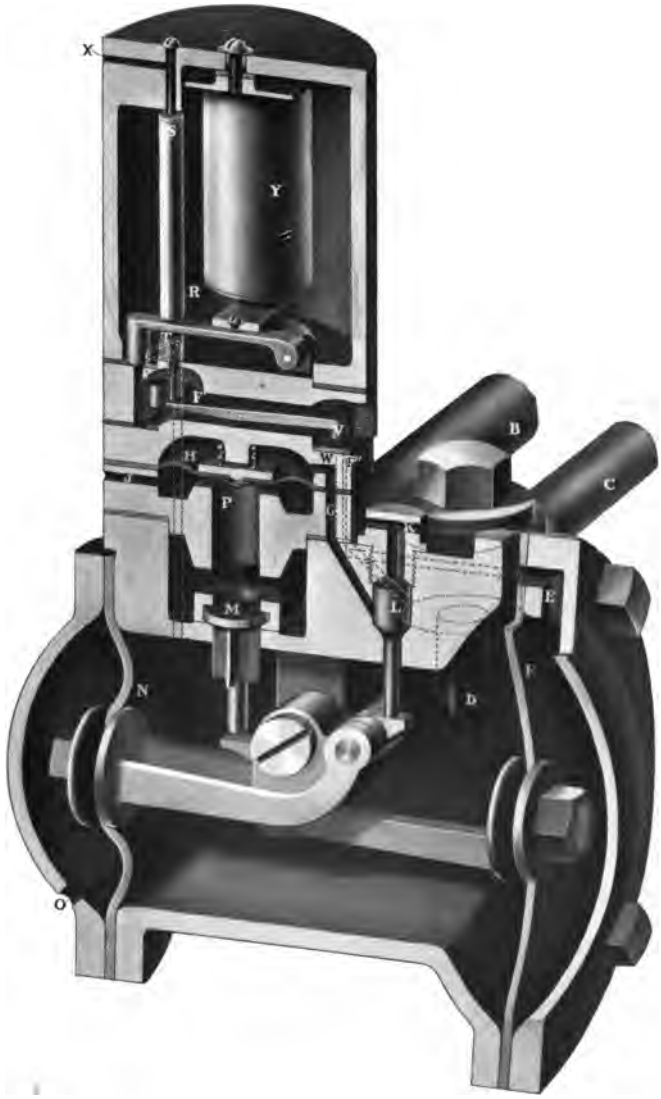


FIG. 74.—EAMES ELECTRIC BRAKE VALVE.

or graduate the application of the brakes on all the cars simultaneously.

2d. A floating fulcrum lever for varying the pressure on the brake shoes, Fig. 75.

It has been explained that the valve was operated by the admission of air to, or the exhaustion of air from, the chamber outside of diaphragm

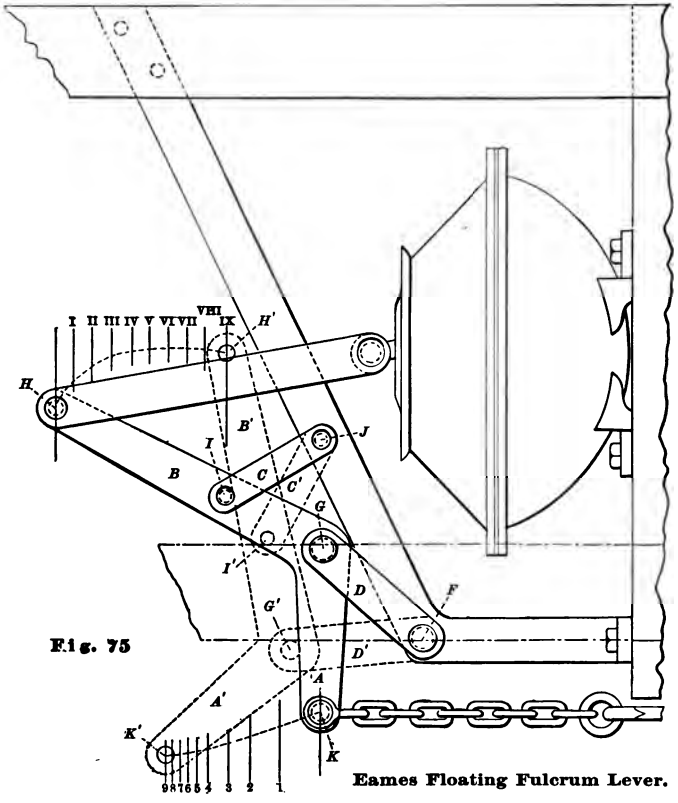


Fig. 75

Eames Floating Fulcrum Lever.

F. This admission and exhaust was made through the ejector and train-pipe. As the flow of air requires an appreciable time, it follows that the brakes on long trains cannot be applied instantly and simultaneously.

If air can be admitted to the chamber outside diaphragm F in all the valves in a train of any length, at the same instant and without any loss of time, it follows that the brakes would be immediately and uniformly applied. To accomplish this was the purpose of the electric device shown with the valve in Fig. 74. This consists of a shell, which is fastened to the main valve with bolts, and contains two chambers, R and F′. Chamber F′ is connected with the space outside of diaphragm F by the passage F″ E. This passage is always open; consequently chamber F′ is virtually a part of the space outside of diaphragm F. Chamber F′ is also connected with the trainpipe by passage W, which is controlled by the valve V. Y is an electro-magnet actuating the armature Z, which moves the valve-stem S T. The valve S controls the admission of the external air to the chamber R through port X; the valve T controls communication between chambers R and F′.

The operation of this electric attachment was as follows: When the electro-magnet Y is magnetized, it raises armature Z, which opens the valve T, and closes the valves S and V. This allows the air which was contained in the chamber R to pass through chamber F′ to the chamber outside of diaphragm F, actuating the valve as already described. The capacity of chamber R is such that one measure of air will apply the brakes lightly — the brakes remaining on as long as the circuit is kept closed. The circuit being broken, valve T closes, and valves S and V open, allowing chamber R to fill with air through port X. A repetition of the movement puts another measure of air into the space outside of diaphragm F, and applies the brakes with proportionally increased force. Breaking the circuit opens valve V, and releases the brakes.

As valve V closes the chamber outside of diaphragm F from the trainpipe, the vacuum in the reservoirs may be increased by the ejector while the brakes are on. To prevent the exhaustion of the air from the center of the shell increasing the relative vacuum upon the inside of diaphragm F and affecting the application of the brakes, air is also exhausted from chamber F′, and consequently from the chamber outside of diaphragm F, through passage I. In this passage is placed the gravity

valve U, which keeps the vacuum in chamber F 1 in. below the vacuum in the reservoir. The same vacuum on both sides of diaphragm F would release the brakes as before explained. A is a check valve to prevent the external air from entering the shell when port X is open.

By this device the engineer could apply and release the brakes instantly and uniformly, either in whole or part, throughout a train of any length. The current was used only when the brakes were applied, and the operation of the valve was not affected if the electric apparatus got out of order.

Fig. 75 shows the floating fulcrum lever, an arrangement for automatically adapting the braking power to the weight of the car and load. The diaphragm washer was connected directly with the brake-levers, and the leverage adjusted to give braking power equal to such percentage of the weight of car as was desirable. This power would be the same, however, whether the car was light or loaded. A certain percentage of the weight of the empty car cannot be exceeded without skidding the wheels, when the car is empty, while a very much greater power may be applied to the loaded car without skidding. This device furnished for empty cars the proper amount of braking power, and increased it proportionally as the car was loaded.

The brake being hung from the body of the car, the slack of the shoes is greater when the car is loaded, because the shoes are hung below the center of the wheels, and retreats from the wheels as the load compresses the springs. The device shown in the cut could be adjusted to increase the pressure on the shoes 50 to 100 per cent. by this variation in the slack.

The lever A B was suspended from the links C and D, which are attached to a rigid support, at F and J. The diaphragm, placed in any convenient position, was connected to the lever at H ; the brake-rod was connected to the lever at K. When the diaphragm was collapsed by exhausting the air from its interior, it drew the lever toward it, the point H traveling over the path H H. At the same time the point X traveled over the path K K′. The numbers show the corresponding position

of the points H and K at different parts of the stroke. During the early part of the stroke, the fulcrum of the lever was at I, while the link D was merely a guide. In the latter part of the stroke, the fulcrum was at G′ and the link C was merely a guide. At intermediate points the fulcrum was at some point between I and G′. Hence, in taking up the slack the brake-rod moved much faster than the diaphragm, and but little force was expanded; while, when the blocks reached the wheels, the stress had increased very much. The spaces between the numbers in the path K—K′ indicate the variation in force, which is inversely as the distance traveled. When the cars were empty the brakes got home at about the point marked 3. When the cars were loaded the brakes got home at about 6, at which point the stress on the brake-rod was about double the stress on the empty car. The cars used in the test weighed 24,000 lbs. empty. Assuming that 70 per cent. of the weight on the wheels was the greatest pressure that could be used without skidding the wheels, 16,800 lbs. would be the limit of pressure that could have been used on the empty car. When loaded, the springs were compressed half an inch. This caused a variation in the slack of ¼ in. The brake-levers were 5 to 1, and the travel of the pull-rod 10 to 1; therefore a variation of ¼ in. in the slack made a variation of 2½ in. in the distance the pull-rod traveled to bring the blocks home. The variation of 2½ in. in the travel of the pull-rod brought the lever to a position where the stress would be about double, or 33,600 lbs. on a loaded car. This result was obtained by inserting the floating fulcrum lever in the pull-rod. The proportion of the parts could be arranged to suit any desired variation, or to take up the slack with a slight expenditure of force and then maintain a uniform pull to the end of the stroke.

Carpenter Brake.

The Carpenter automatic electro air brake was fitted to an Illinois Central engine and 50-car train, each of 40,000 lbs. capacity, and averaging 27,351 lbs. light weight. It consisted of an air pump, main reservoir, etc., on the engine, and a brake-cylinder and auxiliary reservoir underneath each car. The trainpipe was always in direct communi-

THE BURLINGTON BRAKE TRIALS

cation with the auxiliary reservoirs. The brake could be applied by letting air out of the trainpipe, but it could not be released by sending air into the trainpipe. The brake could also be applied or graduated by an electric current which operated an electric valve on each cylinder. Another electric valve was used to release the brake.

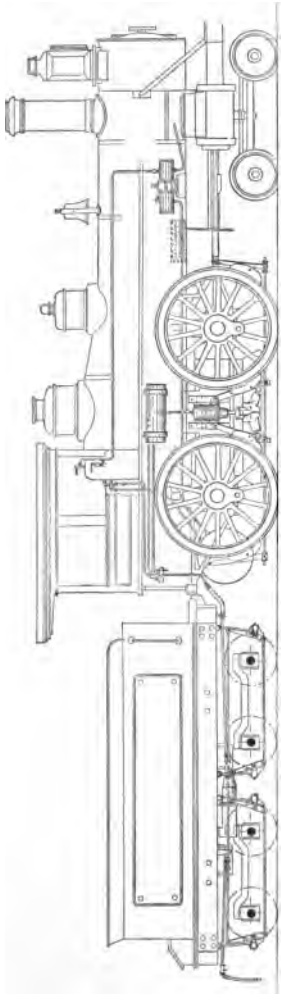


Fig. 76

Fig. 76 shows the general arrangement for an engine and tender. An air-pump placed in any convenient position on the engine compressed the air into the main reservoir ; from thence it passed through the engineer's brake-valve to the tender, and from there on to the rest of the train in the usual way. The detail of the brake apparatus used on the tender was the same as that used for the cars. The detail of the driving-wheel brake apparatus, being so similar to that in common use, needs no further description. The automatic valve for operating the same was placed for convenience under the engineer's cab. A small secondary battery, containing from six to eight cells having one ground connection and one connection to the engineer's brake valve, conveniently located on the engine, furnished the electromotive force for working the valves throughout the train. The handle of the engineer's brake valves having a detachable connection with the plug or slide valve thereof, could be turned to make the electrical connection between

the battery and the train wire without moving the mechanism used to operate the brakes by air ; or the air brake mechanism could be operated without making the electrical connections. The wires extending throughout the train could be laid either within or without the air-pipe, but in either case they were contained within the air-hose, and the simple act of uniting the latter also completed the electrical connections between the cars.

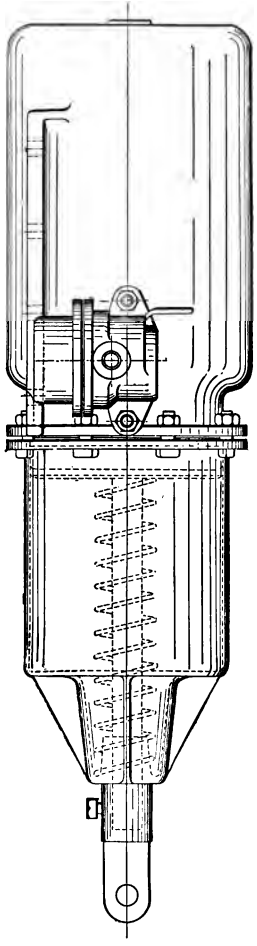


Fig. 77

Figs. 77, 78, and 79 show in detail the arrangement of the brake-cylinder, auxiliary reservoir, and automatic valve. This valvular apparatus contained two distinct main valves, as shown in separate sectional views, Figs. 80 and 81. The first shows section through the brake valve "*a*." This valve was used in applying the brakes, and could be operated either by means of an electric current or by reducing the pressure in the main air-pipe ; in either case air was admitted from the auxiliary reservoir into the brake cylinder applying the brakes. The other view shows section through the release valve "*b*," which could be operated by an electrical current only to release the brakes. In each case an electro magnet, being energized by it, attracted an armature and therewith a small tappet valve ; this exhausted the chamber above the diaphragm, whereupon the pressure beneath the diaphragm raised the latter, and therewith the brake valve "*a*" or the release valve "*b*" applying or

releasing the brake according as the handle of the engineer's valve was thrown forward or backward. To make this valve action clearer we give the following more detailed description: Referring to the engraving (Fig. 80) of section through brake valve "*a*," the air passed from the main pipe to the plug shown by dotted circular lines, thence in between the diaphragm and piston. This pressed the piston down; at the same time the air passed through the piston and into the reservoir. At the same time it passed through a small leak hole into the chamber above the diaphragm. The whole box was then charged with air. When the armature was energized by the electricity passing into the magnet, it lifted a small tapped valve, which blew off the chamber; the air pressure below then raised the diaphragm and the whole brake mechanism, and opened connection to the cylinder. When the valve was dropped by shutting off the electricity, the chamber above the diaphragm was charged again and the valve closed, closing connection between the valve and cylinder, and the brake was applied. Referring to the engraving (Fig. 81) of section through release valve "*b*," in charging the brake-cylinder, the valve chamber in "*b*" was also charged. To release the brakes, the electricity over the release wire energized the magnet in "*b*," which lifted the armature and opened a tapped valve, thus opening connection between the cylinder and the atmosphere, which, of course, threw the brakes off.

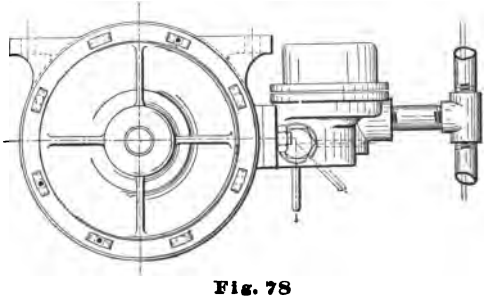


Fig. 78

The valve shown on Fig. 80, while applying and releasing by electricity, was capable only of applying the brakes by variation of the pressure in the main air-pipe. The brake could not be released by raising the pressure in the main air-pipe.

Fig. 82 shows the hose connections, which, while differing from

the Westinghouse coupling, possessed the important advantage of being perfectly interchangeable with it, so that cars equipped with the two different brakes could be coupled together, and as the valves were capable of being operated either by air or electrically, it was evident that the two brakes could interchange without difficulty. It will be seen that in this coupling the electrical connections were entirely within the hose, that the circuit was completed by simply joining the air

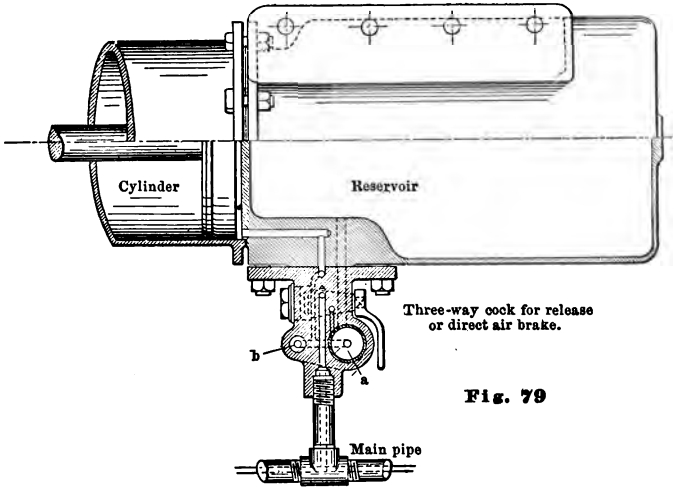


Fig. 79

couplings, and that a hose could be readily replaced, no separate joints having to be made for the electrical wires.

Hanscom Brake.

The Hanscom brake consisted of an air-pump for compressing air; an engineer's brake valve for the distribution of air, two lines of trainpipes and a brake-cylinder under each car, on which was an automatic valve for setting the brake automatically in case the train breaks in two. The brake-cylinders were made longer than the stroke of the piston, so that sufficient air remained in one end to apply the brakes in case of a train breaking in two.

Air Brake Tests

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The engineer's brake valve P (see Fig. 83) was so constructed that when it was in its mid position, which it occupied when the train was running, the air from the pump flowed freely through it into both trainpipes and into both ends of the brake-cylinder, so that the pressure on both sides of the piston was equal. By moving this valve either to the right or left, the air could be released from either end of the brake-cylinder, while the opposite end was in direct communication with the air-pump, and the pressure on that side of the piston could be increased to the extent of the boiler pressure and proportions of the steam and air cylinders of the pump. The automatic valve F was attached to the rear end of the brake-cylinder, and allowed the air to flow freely into the brake-cylinder, but its outflow was retarded by the small valve, which was kept to its seat by a spring. This spring was adjusted to any pressure which it was desired to retain in this end of the cylinder, so that in the event of an accident and the train breaking in two, a sufficient pressure was maintained in this end of the cylinder to set the brakes and stop the train. The trainpipe E had no valve between it and the brake-cylinder, so that the air had free ingress and egress. N is the air-pump; D and E trainpipes; other parts show their functions clearly.

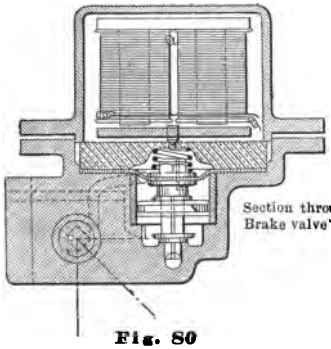


Fig. 80

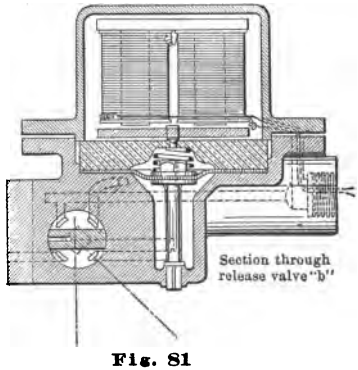


Fig. 81

Card Brake.

The Card was purely an electric brake, applied to 50 Cincinnati, Hamilton & Dayton cars of 50,000 lbs. capacity, and averaging 26,000 lbs. light weight. It is fully described in the subcommittee's report. The passage of an electric current caused two drums under each car to grip one another. One drum was constantly revolving, being driven by a chain from the axle, and the brake-chain was attached to the other drum, consequently, when the latter drum was made to revolve, it wound up the brake-chain and applied the brake. This brake required some special arrangement on the last car of the train, an obvious objection

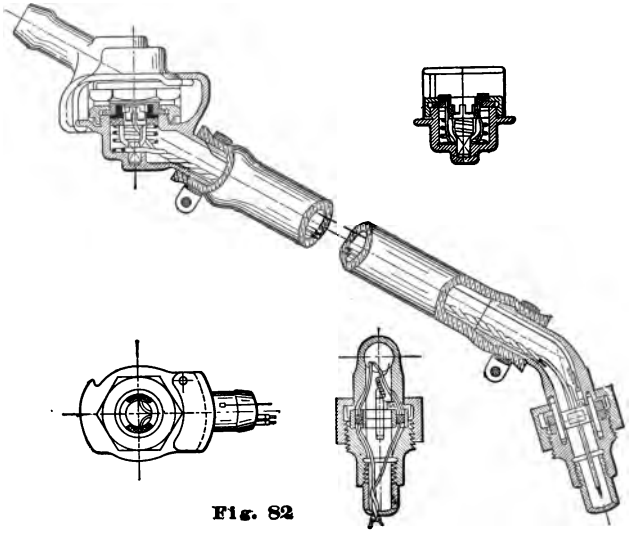


Fig. 82

Carpenter Brake Hose Couplings.

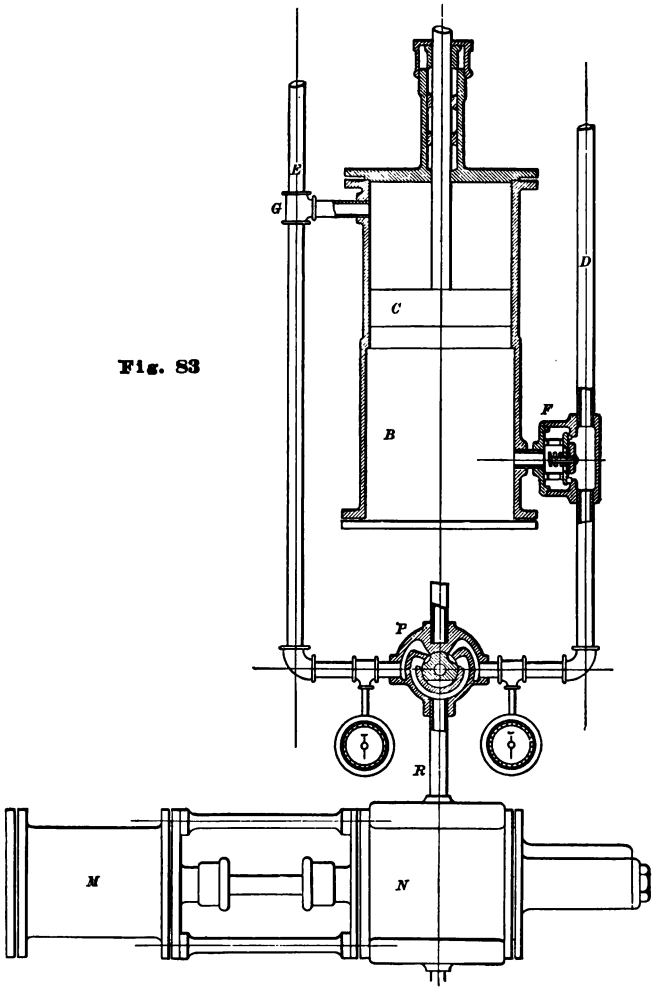
during the introduction of the brake on any road, and in this respect differed from the other brakes.

Report of Electric Appliances.

The following is the report of the subcommittee appointed to report on the various electric appliances, and composed of—

Mr. A. H. Bowman, Electrician, Lehigh Valley Railroad.

Fig. 83



Card Brake.

Mr. E. M. Herr, Acting Superintendent Telegraph, Chicago, Burlington & Quincy Railroad.

Mr. O. E. Stewart, formerly Superintendent Telegraph, Chicago, Burlington & Quincy Railroad, now Superintendent of the East Iowa Division of the Chicago, Burlington & Quincy Railroad.

BURLINGTON, IOWA, May 25, 1887.

Mr. GODFREY W. RHODES, *Chairman M. C. B. Brake Committee:*

In pursuance with the Committee's instructions in letter of May 19, we have made an investigation of the electrical appliances used by the Eames, Carpenter, Westinghouse, and Card brake companies in the 1887 brake test, and respectfully submit the following report:

As to the use made of electricity we find the brakes represented naturally divide themselves into two classes, one in which electricity is entirely depended upon for the proper operation of the braking mechanism, the order in which it is used as an auxiliary or addition to a braking device complete in itself.

In the first class are found the Carpenter Electro Air Brake and the Card Electric Brake.

In the second, the Westinghouse Automatic Air Brake and the Eames Automatic Vacuum Brake.

All the above are arranged on the open circuit system, with the exception of the Card, in which the circuit is closed, but the two batteries, one on the engine and one in the rear car, are so opposed to each other that in the normal condition no current passes through the train. In the open circuit system it is to be understood that unless the brakes are either being applied or released no current is passing or being supplied by the batteries or other electro-generating devices. This is also practically true in the closed circuit system employed by the Card Brake Co.

Taking up in order the four brakes examined, we have, first, the Carpenter Electro Air Brake. The electrical appliances used by this brake company consist of a secondary "Julien" battery of eight cells, carried in a box upon the left-hand side of the engine securely fastened

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to the frame and guide yoke, and two systems of electro-magnets connected in multiple arc upon the three-wire system, one set of magnets operating the admission, the other the release valves. They also exhibited a magneto machine, by means of which the brakes could be operated by the engineer independently of the battery. This machine was not properly adjusted for the work to be done on these tests, and was therefore not used. The brake and release valves referred to above are shown in section on drawing No. 892 of the Carpenter catalogue (Figs. 80 and 81 herewith), in which a full description of the brake mechanism is given. Fig. 84 illustrates the manner in which the electric apparatus mentioned above is connected in this brake system.

In this diagram, B^1 represents the battery; H the handle of the engineer's valve, which closes the circuit A-X by being moved into contact with point A or B Z, by being moved into contact with point B. In the first case, the current would be caused to flow through the magnets M, M^1, M^2, etc., returning by the common return wire C-Y operating the admission valves and applying the brake. In the second case, the flow would be through magnets M_1, M_2, M_3, etc., returning over the same wire C-Y, and operating in like manner the release valves. The connections between the wires on different cars are made automatically in coupling the brake hose by means of contact pieces in the hose coupling, as shown in Fig. 82. These pieces are held in firm contact by a powerful spring, and are well rubbed, in coupling, making a clean, firm contact. The wires are run under the bottom of the cars and through the hose to the couplings.

The resistance of each electro-magnate was found to be 200 ohms, making for a 50-car train when connected as shown a total resistance of 4 ohms. It is worthy of note that, with a battery of constant electro-motive force, the resistance being increased inversely as the number of cars in the train, a constant current strength is maintained through each magnet regardless of the number of cars, making no adjustment necessary for different lengths of train.

With this arrangement of battery and resistance, considerable current is used while the circuit is closed, but as this only takes place while the

pressure is either being increased or decreased in the brake-cylinder, it amounts to but a small consumption of battery, even for a number of stops. Calculations show that with a 50-car train the braking force could be increased or decreased continuously for about 17 hours before the strength of the battery would be destroyed, and a proportionately longer period for a shorter train. From the way in which the circuit is run it is easily seen that, should an accident happen to any of the wires, causing their rupture at any point, the

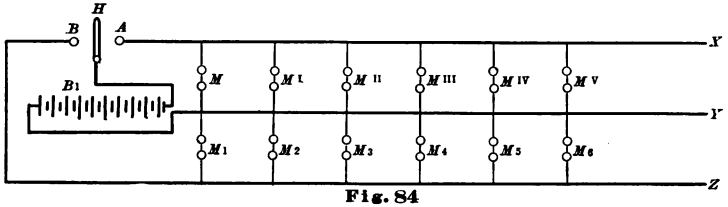

Fig. 84
Carpenter's Electric Apparatus.

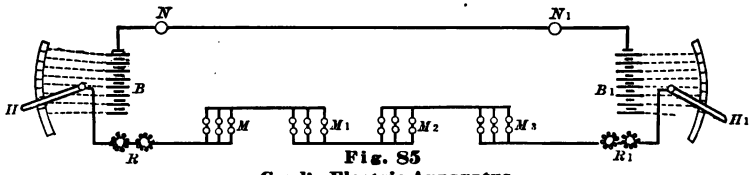

Fig. 85
Card's Electric Apparatus.

brakes between such point and the engine would be unaffected thereby, while those on the other section would, of course, be inoperative. This feature would enable the brakes on the forward section to be released by the engineer in case of an accidental break in two.

We found the conducting wires used fairly well insulated throughout their length except at points where connection was made between wires to valves and the main conductors. No attempt at insulating of these joints is made. Perfect insulation is of great importance in this system, for, should a cross occur between the two conductors, instead of the brakes being applied when an attempt was made to do so, the

release, as well as the admission valves, would be open, and should the current be maintained, the auxiliary reservoir, train-pipe, and main reservoir would all be completely bled. Should either wire come in contact with any metallic connection, either with the trainpipe or any of the braking apparatus, or any part of the car, forming metallic connection with the track, the result would be that either the admission valves would cease to operate by electricity and the brakes could not be set thereby, or, being set, they could not be released, depending upon which wire was touched or grounded.

Rain, sleet, or snow would work very much to the disadvantage of the electric appliances of this brake if the conducting wires are not well and completely insulated. It is, perhaps, fair to say that this brake can be applied by allowing air to escape from the engineer's valve in case the current fails, but cannot be released except by electricity.

In regards to details, we found the electric appliances admirably designed and well worked out, giving, in our opinion, under ordinary circumstances, a good and reliable arrangement. The magnets and armatures are inclosed in the cast-iron cap on top of the valve, but are not within the compressed air chamber. They are separated from the rest of the valve by a heavy brass plate serving to protect the armatures from the magnetic influences of the other iron parts of the valve.

The amount of current used on a 50-car train is about 3 amperes, with an electric motive force of 16 volts, the resistance of the circuit being about 5½ or 6 ohms. Fusible safety plugs are inserted in the circuit next the battery to prevent the possiblity of the magnets being burned.

The next in order is the Card Electric Brake.

This company uses two secondary batteries of a form devised by the inventor, Mr. Card, consisting of 15 cells each, one situated under the engineer's seat on the engine, the other on the rear car of the train, so connected as to oppose each other in such a way that no current passes under normal conditions. Also a system of three electro-magnets for each brake connected in multiple series together with an automatic rheostat current indicator and arrangement for cutting in and out as

many cells as is desired to give the required braking force, all as shown in the diagram, Fig. 85, page 188.

B and B^1 are the batteries, M, M^1, M^2, etc., the systems of electro-magnets, one for each brake, connected as shown; R and R^1 the automatic rheostats, arranged in such a way that, should the train part at any point, the couplings for the wires being so arranged as to close the circuit on each section, thus cutting off part of the resistance before in circuit, an equal resistance would be automatically inserted at the rheostat. This maintains the current at a constant strength, no matter how many or how few cars are broken off. The brake is applied while running, by either the conductor or engineer moving the handle H or H^1, and thus cutting in or out some of the cells, destroying the balance and causing the current to flow through the magnets M, M^1, etc., the amount of flow, and consequent severity of application of the brakes, being regulated by the number of sections over which the handle H or H^1 is moved. The resistance of each magnet is low, being one ohm, making the resistance of the three used in each car $\frac{1}{3}$ ohm, when connected as shown. The total resistance of each car, including conducting wires, is $\frac{1}{2}$ ohm, or a total of 25 ohms for a 50-car train.

Although considerable current is required for the full application of the brakes, only part of it is necessary for a partial application. The current is passing in this system while the brakes are in operation, for not only must the current pass to apply the brakes but it must be maintained to keep them on.

Calculation shows that, with the battery used of a capacity of 10 ampere hours, 10 hours of the maximum application of the brake could be obtained before the battery is exhausted, and, of course, a proportionately longer period for gentler applications.

The conducting wires used by this brake company are not insulated, excepting where they are fastened to the body of the car, and consist of galvanized iron wire cables, $\frac{1}{2}$ in. thick. The couplings are arranged to complete the circuit through one wire by a sliding contact piece in the center, the return current passing through the outside casing of the couplings. They are designed to pull apart at the couplings under

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all circumstance, for, should the hose and contained wires be ruptured, the brakes on neither section could be applied.

The effect of a cross between the conducting wires here would be to apply the brakes throughout the train, and, as no effort has been made to insulate the conducting wires, this is an accident which, in our opinion, is extremely likely to happen either from the direct contact, or by rain, snow, sleet, or other causes. The automatic rheostat is also a delicate piece of mechanism liable to get out of order, with the possible result of burning out some of the magnets, rendering the brake inoperative. The principle on which this brake is gotten up is admirable, but the mechanism employed somewhat complicated for train service.

In the second division, we have, first, the Westinghouse Automatic Air Brake.

The electric device used by this company consists essentially of a valve inserted in the trainpipe, operated by means of compressed air, which raises a piston normally in equilibrium when its balance is destroyed, by blowing off a chamber above it, by means of a small valve raised from its seat by the armature of an electro magnet. The current which energizes this magnet is produced by 6 Le Clanche cells, situated in the box under the engineer's seat. The current is passed through a copper wire insulated with rubber insulation, and run through the trainpipe, the return being through the metal of the pipe itself. The wire is connected automatically in coupling the air-hose, by means of contact pieces in the center of the coupling, giving a firm contact with a slight rubbing between the surfaces. The magnets used are wound to a resistance of 2 ohms each, and but three being used in these tests, the total resistance, about 3½ ohms for the magnets, and about 2 ohms for conducting wire, is 5½ ohms. The battery used would suffice for a long time, as the wires are so connected to the engineer's valve that no electricity would be used, except for emergency stops.

The wires are carefully insulated, and, being inclosed in the trainpipe, are well protected from the effects of the weather. Should a metallic contact occur between the wire and the pipe, however, the result would simply be to render inoperative the electric valves which, as

before stated, are entirely auxiliary to the brake mechanism. The electric features of this brake are well worked out, and, in our opinion, give a reliable and practical apparatus.

The electric appliances to the Eames Automatic Vacuum Brake are also auxiliary to the vacuum mechanism itself. It consists essentially of an electro-magnet inclosed in a cast-iron cap or chamber, which can be put in communication either with the vacuum of the main valve and auxiliary reservoir or with the atmosphere, according as the circuit is made or broken, as explained on page 24 of the Eames catalogue. Also a metallic circuit composed of a single conducting wire and the magnets connected as shown in heavy black lines, plate V, the return being through the rails of the track.

The current is supplied by a small dynamo having an armature 9 in. long and 3 in. in diameter; this dynamo has no governor, and is entirely beyond control, and varies greatly in speed. The magnets, as is seen, are connected in series, making the total resistance equal to the sum of the resistances of the conducting wire and all the magnets, necessitating a very low resistance in the latter ½ ohm each, and a current of considerable strength to overcome the entire resistance, which is for a 50-car train about 30 ohms.

The conducting wire is fairly well insulated, and, being run through the trainpipe, is well protected, except where it is connected to the spiral wire through the hose. The effect of any metallic contact between the conducting wire and the parts of the car in metallic connection with the track would be, as far as the electrical attachment is concerned, to cut out all brakes between this point of such contact and the rear of the train. If the conducting wire be broken or detached, in any way causing a break in the circuit, the entire electric apparatus fails.

No effort was made to protect the armatures from the effect of close proximity of iron in the other parts of the valve, and in several ways the details of the electric attachments might be improved. The use of the track as a return is to be deprecated on account of interruption to the current in case of insulated track sections put in block signal systems, drawbridges, etc.

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It seems to us the whole question of the application of electricity to railroad braking resolves itself into three important questions:

First, can a valve mechanism be made operative by electricity which shall be permanent and practicable for railroad service, not having parts too sensitive or of too fine adjustment? We think it can. The valve construction as shown by Mr. Carpenter, the same which he used in these trials, is certainly not more delicate and complicated than that of the well-known Westinghouse triple valve.

Secondly, can the electrical conductors for working these valves be so insulated and protected as to avoid short circuits and other injuries? We think they can by running the wires inside of the air-pipes where they are as little liable to derangement and injury, and become as permanent and certain in their functions as any other feature of the brake mechanisms. In all the electric brakes shown the wires are laid inside the air-hose couplings, where they are fully protected, and their connections are made from car to car easily and certainly, so that this important point is so far settled as to require no further explanation.

The remaining point is the source of electro-motive force.

Of the different means employed by the companies represented, the secondary battery appears the most reliable, giving a constant current at all times until discharged, recharging being a simple process which can be so methodically and practically arranged as not to interfere with the brake service nor add materially to the expense.

If brakes worked by electricity are to come into general use, it is probable that both battery and dynamo will give way to the magneto generator, being a small machine, about 18 in. square, having an easily-turned crank which instantly develops the electro-motive force required, so that a turn of the crank will actually apply or release the brake. One of these machines was shown us in operation upon an engine and tender brake. This apparatus may solve a most important point connected with the application of electricity to railroad brakes, inasmuch as it renders the apparatus on the locomotive independent of any special stations or round-houses, or any stated period when a battery, if used, would have to be recharged.

We believe, from what we have seen at the Burlington Brake Tests and from a close personal examination of the several electrical arrangements for braking, that electricity properly devised and managed may be made a valuable auxiliary to actuate power brakes on long trains, and their efficiency considerably increased thereby.

A. H. Bowman,
E. M. Herr,
O. E. Stewart,
Subcommittee.

Record of 1887 Tests.

The trials were opened May 9th, and continued without interruption until May 28th or 29th. The Committee were singularly fortunate in being able to go through a prolonged series of tests for a second time without any interference from rain or wind which could be claimed as having an influence on the stops.

The Resistance of Trains.

The following figures give briefly the results of the No. 7 special tests made to determine the frictional resistances of the various trains. The trains were composed of 49 or 50 empty cars with dynamometer and way car, and American type engine and tender. The track and rails were in good condition and the wind light.

Each train was tried once on a slightly descending tangent, and once on a curve, situated on an average descending grade of 506 ft. per mile. The resistance was ascertained on the tangent by running up to stop-post No. 1, at about 20 miles per hour, and then shutting off steam and allowing the train to run until it came to a standstill.

The resistance on the combined grade and curve was ascertained by running the train up to stop-post No. 3 at a low speed (about 5 miles per hour), and then shutting off steam and allowing the train to run until stop-post No. 4 was reached ; the speeds at the moments of passing each stop-post were carefully noted.

It will thus be seen that the resistances given below include not only the resistance of the cars, but of the engine running without steam,

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This is probably greater per ton than that of the cars, but the weight of the engine (about 40 tons) is so insignificant in comparison with that of the cars (700 to 800 tons) that the influence of the engine in running without steam may be neglected, and the resistances given may probably be taken to represent fairly the resistance of new empty cars.

1887.

TABLE XVI.

Pattern of Cars.	Brake.	TANGENT.			CURVE.		
		SPEED.		Resistance, lbs. per ton of 2,000 lbs.	SPEED.		Resistance, lbs. per ton of 2,000 lbs.
		Average Mile.	Mean Mile.		Average Mile.	Mean Mile.	
Pennsylvania .	Westinghouse .	15	15	5.87	19	23¼	8.72
Ill. Cent. . . .	Carpenter . . .	14½	15	6.22	15¾	22¼	9.09
C., B. & Q. . .	Eames	11½	14¼	7.51	13¾	20	11.0
St. Jo. & St. L.	Hanscom . . .	11½	15	12.00	4	4	19.8
Average . .	. . . . .	13¼	15	7.90	16¼	22	9.60

In making this average, the Hanscom results on the curve are excluded as they are not based on sufficient data to be trustworthy. The "mean speed" is the average of the squares of the speeds.

The cars were new, and were tried empty. The Pennsylvania cars were lubricated with dope. The Eames cars when loaded, after these trials, gave trouble from hot boxes. The great resistance of the Hanscom train was caused by the brake shoes binding on the wheels. The brake shoes on the Eames train were also in some cases very close to the wheels and apparently affected the friction of the train on the curve. The brake shoes on the Westinghouse train were hung inside, all the others were hung outside the wheels.

The trials on the curve were made between stop-posts Nos. 3 and 4. About half the total distance is on a 2 deg. 40 min. curve (2,149 ft. radius), extending over nearly a quarter of a circle (80° 40′ 10″),

and the remainder of the distance is on curves averaging about 1 deg. or, say, about 6,000 ft. radius.

The results given in similar trials of brake trains over the same ground in 1886, were as follows; the trains were, however, composed of 25 cars, 12 loaded to their full capacity and 13 empty.

1886.

TABLE XVII.

Pattern of Car.	Brake.	TANGENT.		CURVE.	
		Average speed, miles.	Resistance, lbs. per ton of 2,000 lbs.	Average speed, miles.	Resistance, lbs. per ton of 2,000 lbs.
C., B. & Q. . . .	Westinghouse	20½	4.32	26¼	6.07
I. D. & S. . . .	Eames . . .	16¾	6.84	21¾	9.42
Lehigh Valley . .	Widdifield & Button .	16¾	6.84	21¾	9.42
St. Louis & San Francisco . . .	American . .	11½	8.50	21¼	8.94
Average, 1886		16¼	6.62	22¾	8.46
Average, 1887		13¼	7.90	16¼	9.60
Average of both years		14¾	7.26	19½	9.03

The Committee are indebted to Mr. A. M. Wellington for the calculations giving the results of the trials in 1886.

The results for the two years agree fairly well. The average difference between the resistances on the tangent and on the curve was 1.84 lbs. in 1886, and 1.70 lbs. in 1887. One train of cars (Westinghouse, 1886) gave a resistance of only 4.32 lbs. on the tangent, while another train (Hanscom, 1887) had a resistance of 12.00 lbs. per ton on the tangent, or nearly three times that of the C., B. & Q. cars in the lighter running train. This difference was apparently principally due to the brake-shoes rubbing against the wheels, and was equal to a constant grade against the train of 20 ft. per mile. In running from New York to Chicago, 1,000 miles, the extra resistance would be thus equivalent to surmounting an elevation of 20,000 ft., or more

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than the height of the highest mountain in North America. The importance of keeping the brake-shoes clear of the wheels is thus very evident.

In the 1886 trials, the Chicago, Burlington & Quincy, the Indianapolis, Decatur & Springfield, and the Lehigh Valley trains were composed of cars that had been running some time. The St. Louis & San Francisco cars were new. The C., B. & Q. cars (Westinghouse), and the Lehigh Valley cars, had the brakes hung from the trucks and inside the wheels. All the other cars had the brake shoes hung outside from the body.

The following figures, based on the average results obtained in 1886 and 1887, show the increased friction on the curve, as compared with the tangent.

	Increase, lbs. per ton.
Shoes hung from the truck and inside the wheels . . .	2.30
Shoes hung from the body and outside the wheels . . .	2.84

These results tend to show that the resistance on curves is increased considerably when the shoes are hung outside and too close to the wheels. When the truck swivels, the shoes, being hung from the body, are lifted and brought closer to the wheels by the greater inclination of the hangers. When the shoes are hung from the trucks, no such action occurs, and the shoes remain the same distance from the wheels, whether the car is running on a tangent or on a curve.

The fact that outside-hung shoes rub more forcibly against the wheels on curves is not only shown by the figures given above, but was also observed when the trial trains were being hauled over frogs and curves in the yard at West Burlington.

The size of journal bearing has doubtless an important influence on the friction of trains, and the subjoined figures give the sizes of the journals in three of the trains tried at the 1887 tests, together with the weight of each car, empty, and loaded to its full marked capacity, and the resultant load per square inch on the journals. The bearing area of the journal is assumed as the length and diameter multiplied together.

As the frictional resistance given was obtained with empty cars, where

the load per square inch on the journal is practically identical, the variation found in the resistance is due to other causes than insufficient bearing surface. The highest amount of friction was shown in 1887 by the Chicago, Burlington & Quincy cars, which in 1886 showed the least. In both years the cars were of the same design, but in 1887 the cars were new, whereas in 1886 they had run over 10,000 miles; the difference was, therefore, probably due to less accurate fitting and workmanship as compared with the Pennsylvania and the Illinois Central cars, which were also new, but showed respectively 1.64 and 1.29 lbs. per ton less friction than the Chicago, Burlington & Quincy cars. These differences, insignificant as they may appear, would in running 1,000 miles necessitate an extra amount of haulage power equivalent to surmounting summits 4,330 and 3,415 ft. high respectively, or greater than that of any line between the Mississippi and the Atlantic. The importance of good fitting is further shown by the Chicago, Burlington & Quincy cars running hot when loaded after the resistance test.

TABLE XVIII.

Cars	Journal, length and diameter.	Weight of Car.		Pressure per Square Inch on Journal.		Friction Tangent.
		Empty.	Loaded.	Empty.	Loaded.	
	Inches.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Pennsylvania . .	8×4	30,577	90,577	119	354	5.87
Ill. Cent. . . .	7×4	27,351	67,351	122	301	6.22
C., B. & Q. . .	7×3¾	25,509	65,509	121	312	7.51

The Pennsylvania and Illinois Central cars were built at the company's shops, and the Chicago, Burlington & Quincy cars were built by a contractor. On the other hand, the Chicago, Burlington & Quincy cars, in 1887, were all fitted with new lead-lined journal bearings, which practice rather courts less care in first fitting, while the Pennsylvania had a hard-metal brass and the Illinois Central a babbitt-lined brass. It is not improbable this difference in journal bearings influenced the frictional resistance of each train.

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From these experiments, the following figures, probably, represent the frictional resistance of long trains of freight cars in good repair running over a track in good condition, the weather being fine and warm and the wind light. The resistance appears to be constant at speed of from 12 to 25 miles per hour, and does not appreciably increase with an increase of speed within these limits.

TABLE XIX.— FRICTIONAL RESISTANCE, LBS. PER TON OF 2,000 LBS. SPEEDS 12 TO 25 MILES PER HOUR.

	New Cars.	Old Cars.
	Lbs.	Lbs.
On Tangent	8.00	6.00
On 3° Curve	10.50	8.30

Good lubrication and carefully fitted boxes and journals may, with cars that have been running some time, decrease this resistance to a minimum of 4 lbs. per ton on the tangent, while brake shoes rubbing against the wheels and other unfavorable conditions may increase the friction on the tangent to 12 lbs. per ton, and to considerably more on curves. The use of outside-hung shoes seems to increase the resistance on curves when the shoes are very near the wheels.

Foundation Brake Gear.

A marked improvement in the foundation gear of the competition of 1887 over 1886 will be observed by reference to the accompanying

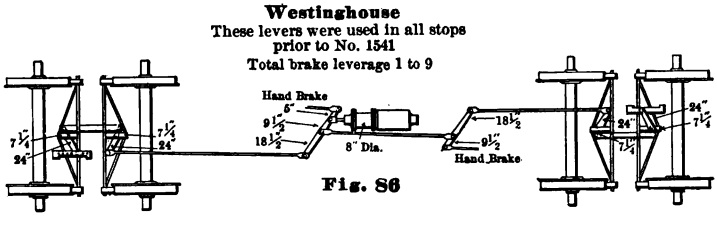


Fig. 86

figures. The Westinghouse Company used cylinder levers of 9½ x 18½ in. prior to stop No. 1541, Fig. 86. In subsequent tests they used

a cylinder leverage as shown by Fig. 87, viz.: 10¼ x 17¾ in.

The ratio which the pressure upon the piston bore to the pressure on the brake shoes was in the first case nearly as 1 to 9, and in the second nearly as 1 to 10.

Westinghouse
These levers were used in stops after No. 1541
Total brake leverage 1 to 10

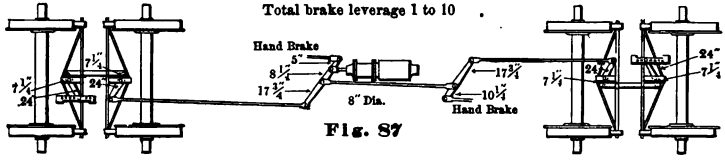
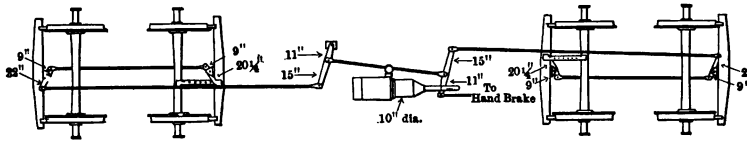


Fig. 87

The same ratio for the Carpenter brake, Fig. 88, was 1 to 10⅕, and for the Hanscom brake, Fig. 89, 1 to 14.1. With the Eames brake, Fig. 90, this ratio varied on account of the floating lever.

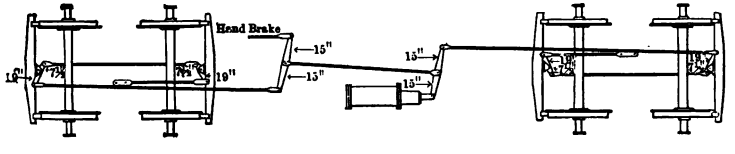
Fig. 88 Carpenter.
Total brake leverage 1 to 10⅕



The Card foundation brake is shown by Fig. 91.

The braking pressure on one car, it will be observed, was only 86.4 per cent. of what it would have been if dead levers had been used,

Fig. 89 Hanscom.
Total brake leverage 1 to 14 1/10



which would have brought an equal pressure on all wheels. Therefore, there was a loss of efficiency of 13.6 per cent.

With the then prevailing general indifference to brake gear on

4-wheel trucks it is not to be wondered that the more difficult application to 6-wheel trucks was hardly attempted.

The loss of efficiency by neglecting to brake the middle wheels of the 6-wheel trucks under passenger equipment theoretically is 33⅓ per cent. This figure was proved by a practical test with a 6-wheeled truck car on the Chicago, Burlington & Quincy Railroad, fitted with the brake connections so arranged that the change from brakes on 4 wheels

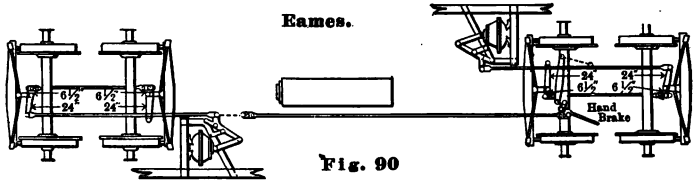


Fig. 90

to brakes on 6 wheels could be easily effected. On many prominent roads the most important trains are equipped almost exclusively with 6-wheel trucks. The needless loss of braking power under these cars has, since the inauguration of these tests, become thoroughly realized and generally remedied.

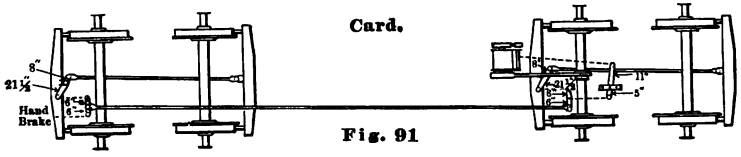


Fig. 91

General Tests.

By reference to the journal of each day's work it will be observed that the first four days were occupied by preliminary tests, such as engine tests, hand-brake tests, train-resistance tests, etc. The Westinghouse Brake Company, on the 5th morning of the tests, May 13th, commenced the general tests with a 50-car empty train — three stops on

level track, with their automatic air brake, 50 empty car train, resulting as follows:

TABLE XX.— 50 WESTINGHOUSE EMPTY CAR TRAIN, 1887.
AUTOMATIC AIR BRAKES.

No. of Stop.	Speed in Miles.	Distance in Feet.	Shock in Inches.	Time in Seconds.	Equivalent Distance at 20 Miles and 40 Miles.	
521	19½	186	103	9¾	196	. .
511	19¼	215	70⅜	11	233	. .
522	36½	588	70½	17	. .	693

These stops may be regarded as phenomenal in their shortness, which becomes all the more evident when we compare them with the best results obtained in 1886.

TABLE XXI.— 50 WESTINGHOUSE EMPTY CAR TRAIN, 1886.
AUTOMATIC AIR BRAKES.

No. of Stop.	Speed in Miles.	Distance in Feet.	Shock in Inches.	Time in Seconds.	Equivalent Distance at 20 Miles and 40 Miles.	
621	23.5	424	Not taken	17½	307	. .
611	20.3	354	do.	16	340	. .
622	40.	922	do.	22½	. .	922
612	40.	927	do.	22¾	. .	927

The brilliancy of the record, however, was completely spoiled by the fearful shock given at the rear end, the slideometer moving, it will be observed, from 70 to 103 inches. The same train was then tested electrically, with the following results:

TABLE XXII.— 50 WESTINGHOUSE EMPTY CAR TRAIN, 1886.
ELECTRIC APPLICATION.

No. of Stop.	Speed in Miles.	Distance in Feet.	Shock in Inches.	Time in Seconds.	Equivalent Distance at 20 Miles and 40 Miles.	
611	21½	160	None.	7	139	. .
531	23	183	do.	8	138	. .
612	38	475	do.	14½	. .	519
532	36½	460	do.	14	. .	545

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Now comes the still more astonishing story. In these electrical stops the slide-ometer never moved, and this with the same cars, the same leverages, and the same pressures, the only difference being the time of application. With the shocks the application commenced on the rear car in from five to six seconds; with the electrical application it was practically instantaneous on every car in the train.

It will, perhaps, be necessary to compare the distances of these stops with other measurements to realize their full significance. Let us take the 138 and 139 ft. of the 20-mile stops. Telegraph poles are generally spaced 33 to the mile, which allows a fraction of over 160 ft. between each pole. The stops were, therefore, made in 22 ft. less than the distance between 2 telegraph poles. Again, each of the Westinghouse cars measured 37 ft., 8 in. from face to face of draw-bar; 133 ft. would therefore be, measuring in freight car lengths, 3 car lengths and 25 ft. The hand-brake stop at the same point with the same cars was made in about 5½ telegraph poles' lengths, or a fraction over 23 freight car lengths. This hand-brake efficiency is much greater than generally found in service, on account of the difference in foundation gear.

The main results of the other 50-car trains are shown on the tables given herewith.

Tabulated Statements.

The tables of this year are chiefly noticeable for the freedom from shocks as compared with the previous year. This becomes all the more prominent when it is borne in mind that with one exception all the stops of 1887 were emergency stops with 50-car trains. An immediate result was a corresponding decrease in accidents; no trucks were jumped from the tracks this year, no king-bolts sheared, and the trains were seldom broken in two. It may be noted that the Westinghouse train was equipped with the Janney coupler; owing to the severity of its earlier shocks, two of these were broken during the trials. The Eames was equipped with the Boston coupler, which is of the vertical plane type; two of these couplers were also broken during the trials.

STOP No. 1. — 20 MILES PER HOUR.

Kind of Stop.	Name of Brake.	Number of Stop.	Train.	Weight, Including Engine and all Cars.	Length of Stop Corrected to 20 Miles per Hour.	Actual Records. Speed.	Distance Stopping.	Time Stopping. Seconds.	Shock.	Remarks.
General No. 7, Engine Tests	1. Carpenter	241	1	167,666	167	23½	231	12	—	
	2. do.	1711	1	167,666	172	21	190	10¼	—	
	3. Westinghouse	1841	1	163,750	194	21½	224	12	—	Automatic.
	4. do.	1831	1	163,750	207	21¼	234	13½	—	do.
	5. do.	111	1	163,750	230	20¾	248	Lost.	—	do.
	6. Eames	1631	1	164,134	231	24	333	16¾	—	Straight Vacuum.
	7. Carpenter	231	1	167,666	237	21¼	268	14	—	
	8. Consol'n No. 434 "Q"	1641	1		254	20	254	15	—	Westinghouse, Automatic.
	9. Westinghouse	221	1	163,750	259	21	286	16½	—	Straight Air.
	10. Eames	311	1	164,134	279	22	338	16¾	—	Automatic.
	11. do.	321	1	164,134	308	23½	425	20½	—	Electric.
	12. American	1521	1	195,750	330	20	330	12¾	—	
General No. 6, Emergency Stops, 50 Empty Car Train, Engine-brakes only	1. Eames	331	51	1,457,814	1,623	20¾	1,747	100½	0.	
	2. Carpenter	251	52	1,547,336	1,869	23	2,472	127½	⅛–⅛	
	3. Westinghouse	121	52	1,731,650	2,524	20¼	2,587	123	0.	Automatic.
General Nos. 1 and 8, Emergency Stops, 50 Empty Car Train, Engine and all Car-brakes and Engine and Hand-brakes	1. Carpenter	751	51	1,535,226	104	23	138	7½	0.	
	2. do.	821	51	1,535,226	104	23	138	6½	0.	
	3. do.	811	51	1,535,226	112	23¼	151	6¾	0.	
	4. Westinghouse	1721	50	1,661,964	130	19½	124	8¼	1.	Electric.
	5. do.	531	51	1,731,650	138	23	183	7¾	0.	do.
	6. do.	631	51	1,731,650	138	22	167	7¾	2.	do. Link Coupled.
	7. do.	611	51	1,731,650	146	21¼	165	7¼	0.	do.
	8. do.	521	51	1,731,650	196	19½	186	9	103.	Automatic.
	9. Eames	731	51	1,439,604	202	22½	254	10¾	0.	Electric.
	10. do.	741	51	1,439,604	226	24	326	13¼	0.	do.
	11. Westinghouse	511	52	1,731,650	232	19¼	215	11½	70⅜	Automatic.
	12. Eames	911	51	1,439,604	287	22	347	15½	0.	Electric.
	13. do.	721	51	1,439,604	294	23½	406	16½	24¼	Automatic.
	14. Card	1211	52	1,506,040	305	19¾	298	16½	0.	
	15. Eames	711	51	1,439,604	308	21¾	364	16¾	20	Automatic.

General Nos. 1 and 8, Emergency Stops, 50 Empty Car Train, Engine and all Car-brakes and Engine and Hand-brakes.	16.	Eames	641	51	1,439,604	309	21¾	366	15½	18⅛		Automatic.	
	17.	Westinghouse	621	51	1,731,650	524	20	524	24½	2		do.	"service."
	18.	C., B. & Q. Hand-brake	351	51	1,457,814	788	20½	828	44	0			
	19.	Hanscom	841	51	1,404,367	802	21½	927	47½	0			
	20.	P. R. R. Hand-brake	211	52	1,731,650	874	22	1,057	50¾	0			
	21.	Ill. Cent. do.	271	51	1,546,986	959	20	959	50½	0			
General No. 2, Emergency Stops, 50 Mixed Car Train, Engine and all Car-brakes	1.	Carpenter	1621	52	2,960,335	138	20½	145	8¾	3⅛			
	2.	do.	1011	52	2,960,335	143	19½	136	9¾	¾			
	3.	do.	941	52	2,894,327	165	21½	191	10½	¼			
	4.	Westinghouse	1121	52	3,282,650	174	21½	201	11¼	0		Electric.	
	5.	do.	1111	52	3,282,650	187	20¾	201	11¼	0		do.	
	6.	Eames	1221	51	2,759,604	219	19¼	203	12	0		do.	
	7.	do.	1241	52	2,798,714	245	15½	147	11¼	0		do.	
	8.	do.	1311	51	2,759,604	289	20¾	311	15¾	0		do.	
	9.	do.	1321	52	2,798,714	398	21	439	21¼	4½		Automatic.	
	10.	do.	1341	52	2,798,714	458	18¾	403	22	3½		do.	
General No. 5, Emergency Stops, 50 Mixed Car Train, Slack Shoe Test, all brakes	1.	Westinghouse	1351	52	3,282,640	171	21½	198	11¼	0		Electric.	
	2.	Carpenter	1051	52	2,960,335	201	20	201	12½	1¾			
	3.	Eames	1431	52	2,798,714	434	22	525	24½	7		Automatic.	
Extra Test, No. 1, Emergency Stops	1.	Westinghouse (11 Empty Freight Cars)	1751	13	539,196	30 m. 304	31½	335	12¼	0		Automatic.	
	2.	do.	1741	13	539,196	325	32½	382	13¼	0		do.	
Eight Coach Trains with old Westinghouse Brakes and 11 Freight Car Train with 1887 Westinghouse Brakes	3.	do.	1731	13	539,196	334	31½	368	13½	0		do.	
	1.	Westinghouse (8 Co'hes, Stop Train)	1461	10	536,000	409	34½	541	18¼	0		do.	
	2.	do.	1441	10	536,000	477	33	577	20½	0		do.	
	3.	do.	1451	10	536,000	483	32	550	19¾	0		do.	
Extra Test, No. 2, Emergency Stops, 25 C., B. & Q. old Air-brake Cars Empty		Westinghouse	1511	27	778,000	20 m. 308	20½	324	14¼	14½		Automatic.	
Extra Test, No. 3, Emergency Stops, 25 Empty Car Train, Westinghouse new triples	1.	Westinghouse	1541	27	967,255	144	23½	199	9	29⅜–1		Automatic.	
	2.	do.	1551	27	967,255	170	22	206	9¾	29⅜		do.	
	3.	do.	1651	27	967,255	—	23	—	—	12¾		do.	
	4.	do.	1661	26	928,145	—	22	—	10¼	21¼		do.	
	5.	do.	1871	26	935,610	164	21	181	10½	23½		do.	
	6.	do.	1861	27	967,255	171	20½	180	10	25½		do.	

NOTE. — Where several methods of applying brakes exist, the one used is noted in remarks column

STOP No. 2.—40 MILES PER HOUR.

Kind of Stop.	Name of Brake.	Number of Stop.	Train.	Weight, Including Engine and all Cars.	Length of Stop Corrected to 40 Miles per Hour.	Actual Records. Speed.	Distance Stopping.	Time Stopping. Seconds.	Shock.	Remarks.
General No. 7, Engine Tests	1. Carpenter	1712	1	167,666	631	40½	647	21	—	
	2. do.	242	1	167,666	692	40½	710	23	—	
	3. American	1522	1	197,750	763	38½	708	21	—	
	4. Eames	1632	1	164,134	842	41¼	896	27¾	—	Straight Vacuum.
	5. Westinghouse	1852	1	163,750	859	41¼	914	31½	—	Automatic.
	6. do.	222	1	163,750	880	42	970	28½	—	Straight Air.
	7. Consol'n No. 434 "Q"	1642	1	. . .	904	40	904	28¾	—	Westinghouse Automatic.
	8. Westinghouse	1842	1	163,750	914	41	960	33½	—	Automatic.
	9. do.	112	1	163,750	984	41	1,034	30	—	do.
	10. Eames	322	1	164,134	1,048	40¼	1,061	31½	—	Electric.
	11. do.	312	1	164,134	1,058	41	1,122	31	—	Automatic.
	12. Carpenter	232	1	167,666	1,187	41½	1,278	35½	—	
General Nos. 1 and 8, Emergency Stops, 50 Empty Car Train, Engine and all Car-brakes and Engine and Hand-brakes.	1. Carpenter	822	51	1,535,226	377	37½	332	10¾	0	
	2. do.	812	51	1,535,226	404	35½	318	12	0	
	3. do.	752	51	1,535,226	457	32½	302	11	0	
	4. Westinghouse	1722	50	1,661,964	473	38¼	433	13½	0	Electric.
	5. do.	532	50	1,731,650	523	37½	460	14	0	do.
	6. do.	612	50	1,731,650	526	38	475	14¼	0	do.
	7. Eames	732	50	1,439,604	695	41	626	16½	0	do.
	8. Westinghouse	522	51	1,731,650	706	36½	588	16	70½	Automatic.
	9. Eames	722	51	1,439,604	939	40	939	21½	20¾	do.

General Nos. 1 and 8, Emergency Stops, 50 Empty Car Train, Engine and all Car-brakes and Engine and Hand-brakes.	10. Eames	712	51	1,439,604	952	38½	883	21¾	19½	Automatic.	
	11. do.	642	51	1,439,604	973	38¼	890	21¼	15⅜	do.	
	12. Westinghouse	622	51	1,731,650	1,177	37	1,007	27½	11¾	do.	"services."
	13. Card	1212	52	1,506,040	1,337	35½	1,053	38	0		
	14. C. B. & Q., Hand-brake	352	51	1,457,814	2,622	30	1,475	55½	0		
	15. Hanscom	842	51	1,404,367	2,712	30	1,532	56¾	0		
	16. P. R. R., Hand-brake	212	51	1,731,650	2,765	30¼	1,699	59	0		
	17. Ill. Cent., do.	272	51	1,546,986	3,170	29¾	1,753	68½	0		
					30 m.						
General No. 2, Emergency Stops, 50 Mixed Car Train, Engine and all Car-brakes	1. Carpenter	1622	52	2,960,335	366	30¼	372	14¾	2½		
	2. do.	1012	52	2,960,335	400	30	400	15½	½		
	3. Westinghouse	1122	52	3,282,650	422	32½	495	17¾	0	Electric.	
	4. Carpenter	942	52	2,894,327	426	34¾	572	19¾	0		
	5. Westinghouse	1112	52	3,282,650	444	32	505	18¾	0	Electric.	
	6. Eames	1222	51	2,759,604	461	30	461	17½	0	do.	
	7. do.	1242	52	2,798,714	537	31	574	20¾	0	do.	
	8. do.	1312	51	2,759,604	554	32½	650	21¾	0	do.	
	9. do.	1322	52	2,798,714	754	31	805	26¾	5½	Automatic.	
	10. do.	1342	52	2,798,714	836	31½	922	29¾	2	do.	
					30 m.						
General No. 5, Emergency Stops, 50 Mixed Car Train, Slack Shoe Test, all brakes	1. Westinghouse	1352	52	3,282,640	453	31	484	18¼	0	Electric.	
	2. Carpenter	1052	52	2,960,335	510	30	510	20½	1¼		
	3. Eames	1432	52	2,798,714	828	31½	913	31	5½	Automatic.	
					40 m.						
Extra Test, No. 1, Emergency Stops	1. Westinghouse	1752	13	539,196	502	41¼	534	15½	0	do.	
Eight Coach Trains with old Westinghouse Brakes and 11 Freight Car Train with 1887 Westinghouse Brakes	2. do. 11 cars.	1742	13	539,196	562	40	562	16	0	do.	
	3. do.	1732	13	539,196	580	41½	624	17¾	0	do.	
	4. do.	1442	10	536,000	832	43	961	27¼	0	do.	
	5. do. 8 coaches.	1452	10	536,000	869	44½	1,075	28¼	0	do.	
Extra Test, No. 2, Emergency Stops, 25 C., B. & Q. old Air-brake Cars Empty	Westinghouse	1512	27	778,000	770	43	890	25	17⅜	do	

NOTE.— Where several methods of applying brakes exist, the one used is noted in remarks column.

STOP No. 3.— 20 MILES PER HOUR.

Kind of Stop.	Name of Brake.	Number of Stop.	Train.	Weight, Including Engine and all Cars.	Length of Stop Corrected to 20 Miles Per Hour.	Actual Records. Speed.	Distance Stopping.	Time Stopping. Seconds.	Shock.	Remarks.
General No. 7, Engine Tests	1. Carpenter	243	1	167,666	188	21¼	212	12	—	
	2. Westinghouse	1853	1	163,750	202	21½	233	13¼	—	Automatic.
	3. Carpenter	1713	1	167,666	209	21½	241	13¾	—	
	4. Westinghouse	223	1	163,750	235	21	259	14½	—	Straight Air.
	5. American	1523	1	195,750	251	22	304	14½	—	
	6. Eames	1633	1	164,134	256	22	310	16¾	—	Straight Vacuum.
	7. Westinghouse	113	1	163,750	260	21½	300	15½	—	Automatic.
	8. Consol'n No. 434 "Q"	1643	1	. . . .	277	23	366	19	—	Westinghouse Automatic.
	9. do. 122 do.	1533	1	161,050	281	23	371	19½	—	do. do.
	10. Carpenter	233	1	167,666	300	22	363	17½	—	
	11. Eames	313	1	164,134	320	23½	442	21½	—	Automatic.
	12. do.	323	1	164,134	333	22½	422	21¾	—	Electric.
General Nos. 1 and 8, Emergency Stops, 50 Empty Car Train, Engine and all Car-brakes and Engine and Hand-brakes.	1. Carpenter	823	51	1,535,226	108	22½	137	7	0	
	2. do.	813	51	1,535,226	123	21½	142	7¼	0	
	3. do.	753	51	1,535,226	131	23	173	8¼	0	Electric.
	4. Westinghouse	1723	50	1,661,964	135	22½	171	8½	0	do.
	5. do.	613	51	1,731,650	139	21½	161	8	0	do.
	6. do.	533	51	1,731,650	162	20½	170	8	0	do.
	7. Eames	733	51	1,439,604	234	21	258	12¼	0	do.
	8. do.	723	51	1,439,604	332	21	366	17¾	25½	Automatic.
	9. do.	643	51	1,439,604	338	21¼	382	17¾	20¼	do.

General Nos. 1 and 8, Emergency Stops, 50 Empty Car Train, Engine and all Car-brakes and Engine and Hand-brakes.	10. Eames	713	51	1,439,604	351	21½	406	17	22	Automatic.
	11. do.	913	51	1,439,604	380	21	419	19	12½	Electric.
	12. Westinghouse	623	51	1,731,650	422	21½	488	20¼	13¾	Automatic "service."
	13. Card	1213	52	1,506,040	580	20¼	595	31	0	
	14. C. B. & Q. Hand-brake	353	51	1,457,814	876	20	876	46½	0	
	15. P. R. R. do.	213	52	1,731,650	944	21¾	1,117	50½	0	
	16. Ills. Cent. do.	273	51	1,546,986	1,167	19¾	1,138	57¾	0	
	17. Hanscom	843	51	1,404,367	1,167	22	1,412	74½	0	
General No. 2, Emergency Stops, 50 Mixed Car Train, Engine and all Car-brakes	1. Carpenter	1623	52	2,960,335	135	21	149	8¾	0	
	2. Westinghouse	1823	52	2,960,335	149	22½	189	9¼	0	Electric.
	3. do.	1123	52	3,282,650	197	22½	250	13	0	do.
	4. do.	1113	52	3,282,650	197	22	238	13	0	do.
	5. Carpenter	1013	52	2,960,335	201	22	243	13¾	½	
	6. do.	943	52	2,894,327	202	21¼	228	13¼	¼	
	7. Eames	1223	51	2,759,604	219	21	241	13½	0	Electric.
	8. do.	1243	52	2,798,714	251	23¼	339	16¾	0	do.
	9. do.	1313	51	2,759,604	274	22	331	16	0	do.
	10. do.	1323	52	2,798,714	427	21½	494	23	5⅛	Automatic.
General No. 5, Emergency Stops, 50 Mixed Car Train, Slack Shoe Test, all brakes	1. Westinghouse	1353	52	3,282,640	197	22½	250	14	0	Electric.
	2. Carpenter	1053	52	2,960,335	282	21½	326	17¾	½	
	3. Eames	1433	52	2,798,714	473	23	626	26½	6	Automatic.
Extra Test, No. 1, Emergency Stops	1. Westinghouse, 11 Cars	1733	13	539,196	370 (30 m.)	33	448	15½	0	Automatic.
Eight Coach Trains with old Westinghouse Brakes and 11 Freight Car Train with 1887 Westinghouse Brakes	2. do. 8 Coaches	1443	10	536,000	598	28½	540	21	0	do.
Extra Test, No. 2, Emergency Stops, 25 C., B. & Q. old Air-brake Cars Empty.	Westinghouse	1513	27	778,000	273 (20 m.)	21½	315	15¼	16⅜	do.

NOTE — Where several methods of applying brakes exist, the one used is noted in remarks column.

STOP No. 4.—40 Miles per Hour.

Kind of Stop.	Name of Brake.	Number of Stop.	Train.	Weight, Including Engine and all Cars.	Length of Stop Corrected to 40 Miles per Hour.	Actual Records. Speed.	Distance Stopping.	Time Stopping. Seconds.	Shock.	Remarks.
General No. 7, Engine Tests	1. Carpenter	1714	1	167,666	698	42	770	23¼	—	
	2. do.	2441	1	167,666	739	36	598	21½	—	
	3. Westinghouse	1854	1	163,750	806	42¾	920	26¾	—	Automatic.
	4. Carpenter	2442	1	167,666	912	45½	1,180	31	—	
	5. Eames	1634	1	164,134	947	41	995	28¼	—	Straight Vacuum.
	6. American	1524	1	195,750	949	38½	881	25¼	—	
	7. Westinghouse	224	1	163,750	958	41	1,007	31½	—	Straight Air.
	8. Consol'n No. 434 "Q"	1644	1		1,016	40	1,016	31½	—	Westinghouse Automatic.
	9. do. 122 do.	1634	1	161,050	1,056	34	763	30	—	do. do.
	10. Eames	324	1	164,134	1,281	40¾	1,330	38¼	—	Electric.
	11. Westinghouse	1142	1	163,750	1,290	40½	1,323	37½	—	Automatic.
	12. Eames	314	1	164,134	1,324	40¾	1,374	36¼	—	do.
	13. Carpenter	234	1	167,666	1,501	40	1,501	44	—	
General No. 1 and 8, Emergency Stops, 50 Empty Car Train, Engine and all Car-brakes and Engine and Hand-brakes.	1. Westinghouse	1724	.	1,161,964	463	43	535	14	o	Electric.
	2. Carpenter	754	51	1,535,226	521	41¼	568	16	o	do.
	3. do.	824	51	1,535,226	546	41	574	16¼	o	
	4. do.	814	51	1,535,226	564	41	593	17	o	
	5. Westinghouse	614	51	1,731,650	571	43	660	16½	o	Electric.
	6. do.	534	51	1,731,650	578	41¼	615	16½	o	do.
	7. Eames	914	51	1,439,604	653	39½	637	17	o	do.
	8. do.	734	51	1,439,604	759	40¾	788	20	o	do.
	9. do.	724	51	1,439,604	1,047	41	1,100	25¼	23¾	Automatic.

General Nos. 1 and 8, Emergency Stops, 50 Empty Car Train, Engine and all Car-brakes and Engine and Hand-brakes.	10.	Eames	644	51	1,439,604	1,049	42½	1,185	27½	16⅝		Automatic.
	11.	do.	714	51	1,439,604	1,067	41¾	1,163	26	20½		do.
	12.	Westinghouse	624	51	1,731,650	1,357	40¼	1,374	32½	14		do. "service."
	13.	Card	1214	52	1,506,040	1,690	37¼	1,700	50	0		
	14.	Ills. Cent. Hand-brake	274	51	1,546,986	3,713	31	2,230	72	0		
	15.	C., B. & Q. do.	354	51	1,457,814	3,900	29¾	2,157	70¾	0		
	16.	P. R. R. do.	214	52	1,731,650	4,223	29¾	2,336	74½	0		
	17.	Hanscom	844	51	1,404,367	6,432 30 m.	34½	4,800	135	0		
General No. 2, Emergency Stops, 50 Mixed Car Train, Engine and all Car-brakes	1.	Carpenter	1624	52	2,960,335	360	34	462	16¾	2½		
	2.	Westinghouse	1824	52	2,960,335	369	33½	460	16¼	0		Electric.
	3.	Eames	1244	52	2,798,714	490	40	872	28	0		do.
	4.	Westinghouse	1124	52	3,282,650	525	33¼	645	22	0		do.
	5.	do.	1114	52	3,282,650	531	33	643	22½	0		do.
	6.	Carpenter	1014	52	2,960,335	566	33¾	717	25	1½		
	7.	Eames	1224	51	2,759,604	585	31	625	21¾	0		Electric.
	8.	Carpenter	944	52	2,894,327	592	36½	876	29	½		
	9.	Eames	1314	51	2,759,604	685	30¾	720	24	0		Electric.
	10.	do.	1324	52	2,798,714	973 30 m.	31	1,039	32¼	7¾		Automatic.
General No. 5, Emergency Stops, 50 Mixed Car Train, Slack Shoe Test, all brakes	1.	Westinghouse	1354	52	3,282,640	548	33	663	22¾	0		Electric.
	2.	Eames	1434	52	2,798,714	853	35	1,161	37½	0		Automatic.
	3.	Carpenter	1054	52	2,960,335	1,018	33	1,232	42½	2½		
Extra Test, No. 1, Emergency Stops	1.	Westinghouse, 11 Cars	1734	13	539,196	641	42½	723	19¼	0		Automatic.
Eight Coach Trains with old Westinghouse Brakes and 11 Freight Car Train with 1887 Westinghouse Brakes	2.	do. 8 Coaches	1444	10	536,000	956	41	1,004	28½	0		
Extra Test, No. 2, Emergency Stops, 25 C., B. & Q. old Air-brake Cars Empty		Westinghouse	1514	27	778,000	824	43	952	25	21⅝		

NOTE.— Where several methods of applying brakes exist, the one used is noted in remarks column.

The Carpenter train was equipped with the ordinary link-and-pin draw-bar which was not wedged up during the great majority of the trials and suffered no damage. The casualties due to the continuous brakes were inconsiderable as compared with last year, and show in the strongest possible way the benefits that may be obtained in freight-train service by more efficient brakes, together with the elimination of slack from the couplings. The pressure columns give interesting figures, and to get an intelligent appreciation of the work of the varoius competitors, is deserving of the most careful study. It will be seen that the middle car brake-beam force of the Carpenter brake is enormously high, considerably above the light weight of the cars, viz.:

Average light weight of Illinois Central car, 27,351 lbs.

Middle car brake-beam force 30,000 to 34,000 lbs.

With the Westinghouse the reverse is the case. Average light weight of Pennsylvania Railroad car, 27,351 lbs.

Middle car brake-beam force 19,000 to 23,000 lbs.

The highest pressure carried by the Westinghouse Co. was in their stops 1823 and 1824. Unfortunately, the diagrams of these two stops were mislaid, and comparisons therefore cannot be made. Notwithstanding these low Westinghouse pressures, they nevertheless exerted sufficient power to slide wheels on dry rails.

The Eames pressures were close to the light weight of the cars, sometimes slightly exceeding it. The record under the heading of "wheel sliding" is not to be accepted as reliable, but merely as giving an approximate idea of the extent to which wheels were slid. As in 1886, no wheels were flattened sufficiently to justify their removal. The Chicago, Burlington & Quincy Railroad Company, in purchasing the Eames cars after the contest, accepted the wheels without taking exception to any. The Illinois Central on receiving their cars back at Chicago condemned one pair on account of flat spots from sliding.

Series B, 1887, plate VI., groups the competitors under each competition, ranking them in accordance with the shortness of stop, regardless of other considerations. It will be seen that this year the hand brakes again succeeded in doing better work than one of the competitors.

Air Brake Tests

THE BURLINGTON BRAKE TRIALS

In stops 3 and 4 of competition No. 1, the hand brakes of the Pennsylvania, the Illinois Central, and the Chicago, Burlington & Quincy cars all proved more efficient than the Hanscom automatic brake. Tests 621, 622, 623, and 624 of the Westinghouse, it will be observed, are service stops, while those of its competitors are all emergency stops.

Towards the end of this table, plate VI., it will be seen tests were made with an eight-car passenger train made up of 8 old Chicago, Burlington & Quincy coaches, and also a train made up of 11 Westinghouse freight-cars with the new triple, these proportions making trains of about corresponding weights. The difference in length of stop indicates the improvements that may be made in passenger train stops by the introduction of quicker acting triples.

The last series of tests were made by the Westinghouse Company with some new triples constructed since the commencement of the tests with the hope of overcoming the objectionable shocks in emergency stops, with their 50-car train when operated atmospherically. Reference to the slideometer column shows this has not been accomplished, though less than 30 cars composed the train.

Owing to the various capacities of the competitors' cars, and consequent various light weights, a question arose early in the contest as to what should constitute a basis for the load of each in the mixed car train.

In determining the efficiency of a brake the proportion of the brake power to the total weight of the train is an important factor.

With equal velocities, the total energy of any moving body is proportional to its weight, and to obtain comparative resistances in destroying the motion of trains by brakes, the force of the brakes should be proportional to the weight, and conversely the total load for a test train should be in proportion to the brake force.

In order to get the best efficiency, it is the regular practice to make the brake power equal to the weight of the empty car.

The competing companies at Burlington could safely do this, for they were always sure of a dry rail. The committee, therefore, decided

AVERAGE RESULTS BURLINGTON FREIGHT BRAKE TESTS, 1887. EMERGENCY STOPS.

The distances corrected for the exact speeds noted, and for level grade.

Series C — 1887. Plate VII.

Kind of Stop.	Name of Brake.	Speed. Miles.	Distance. Feet.	TIME. From Brake Applied by Engineer. Rear Car. Brakes Begin to Apply. Seconds.	Brakes Fullyon. Seconds.	From Full Stop. Brakes Off Rear Car. Seconds.	Train Moving. Min.	Sec.	From Release Signal till Full Release, Rear Car. Seconds.	Total Number of Cars Released by Hand.	TRAIN. Total Weight—Engine, Cars and Load. Tons.	Per Cent. Braked.	PRESSURES. Before Stop Trainpipe. Lbs.	Cylinder, Rear Car. Lbs.	Brake Beam Pressure Per Cent. Weight of Empty Car.	MISCELLANEOUS. Slidometer Movement, Rear Car, Least and Greatest. Inches.		Total Number of Couplings Broken.	Brake Casualties.	Wheels Slid — Distance.
50 Empty, Air	Westinghouse	20	213	5	—	14½	34		—	1	865	93.4	72½	—	72	70⅜	103	1		
		40	723	6	—	—	23	50	—	0	865	93.4	73	—	69	70½		0		30
	Eames	20	304	10¼	—	19½		54¾	19	0	719	93.7	9¾	6	90	18⅜	25½	0		195
		40	935	10½	17½	19	1	47⅛	19½	0	719	93.7	9½	5¼	89	15⅜	23¾	0		250
50 Empty, Electric	Carpenter	20	111	1½	4	1¼	1	13	1½	1	768	90.6	64	36¼	106	0		0		3
		40	457	1¼	4½	¾	1	9	1¼	1	768	90.	61	37½	104	0		0		6
	Westinghouse	20	143	—	—	36	2	20	33½	0	866	93.4	70	—	69	0		0		11
		40	527	—	—	40½	1	46½	39½	0	866	93.4	73	—	71	0		0		5
	Eames	20	253	4	9	17½	4	47	15½	20	720	94.	10	5	—	12½		1	Electrical connections proved very faulty, giving considerable trouble, and after stop 741 the run had to be given up on account of electrical connections on the engine burning out. It was also impossible to release the brakes on 20 cars.	130
		40	621	2¾	7	8	1	22	8	0	720	94.	9½	5¼	—	0		0		220
50 Mixed, Electric	Carpenter	20	171	1	3½	1	2	4	⅞	2	1,463	47.	69	38	100	¼	¾	0	Four cars cut out for defects in the release valves, and one on account of broken brake rod	105
		30	457	1	4	1½	1	53	1⅜	1	1,463	46.6	65	37	93	0	½	0		212
	Westinghouse	20	182	½	3⅜	59½	2	32	57½	0	1,641	49.3	82	60½	60½	0		0		10
		30	448	½	4	79¾	7	40	74	2	1,641	49.3	83	61	65¼	0		0		10
	Eames	20	254	1½	7	8¼	1	44	—	0	1,390	49.2	10¼	6	90½	0		0		111
		30	528	2½	7½	12¾	2	34½	18	0	1,390	49.2	10	5½	96½	0		0		335
50 Mixed Slack Shoes. Electric	Carpenter	20	229	1	4½	2½		37½	1¾	0	1,480	48.4	60¼	28	—	½	1¾	0		140
		30	648	1	3¾	¾		46	1¼	0	1,480	48.4	54	24	—	1¾	2½	0		225
	Westinghouse	20	178	¾	4½	51½	2	26	52½	0	1,641	49 3	85	62½	69½	0		0		107
		30	466	1	5	63½	2	41½	48½	0	1,641	49.3	83	61½	70	0		0		225
Air	Eames	20	421	12	18	22	3	55	24	0	1,399	48.8	10¼	6	106	6	7	1	Two hose became uncoupled owing to being too short. In two cars the load of wheels shifted during stop 1432	205
		30	769	12	24	34½			28	0	1,399	48.8	9¾	5½	103	0	7	1		125
50 Mixed, Air	Eames	20	410	11	15½	20	2	2¾	29¼	0	1,399	48.8	10⅛	6	97.6	3½	5⅛	0		246
		20	799	11	17¾	35¾	2	57	36½	0	1,399	48.8	9⅞	5¾	95	2	7¾	0		516

THE BURLINGTON BRAKE TRIALS

that the brake power on the different cars should be taken as equal to their light weight, and that the cars should be loaded in proportion to their light weight, the load for the lightest being 40,000 lbs.

The Eames cars, weighing 25,600 lbs., were loaded with 40,000 lbs.

The Carpenter cars, weighing 27,350 lbs., were loaded with 42,800 lbs.

The Westinghouse cars, weighing 30,577 lbs., were loaded with 47,700 lbs.

The ratio of brake power to the total load being 39 per cent. in each case.

But as no restrictions were laid down regarding the leverage or pressures, each contestant still had considerable latitude as to what force should be used against the wheels to better any series of stops over those of a competitor. In looking over these tables, therefore, while the column headed "Weight, including Engine and Cars" should be carefully noted, the pressure existing before the stops were made deserve equal consideration.

Stops 1823 and 1824 of the Westinghouse, and 1623 and 1624 of the Carpenter, are deserving of special attention, as it will be seen that, in these stops, the gross weight of each train was made the same; maximum pressures were also used, each company endeavoring to make a minimum stop.

Series C., 1887, plate VII., still further condenses the results. It deals only with the averages made by the Carpenter, the Eames, and the Westinghouse trains. It will be observed the Eames is the only train going through all the tests prescribed, both with its atmospheric and electric appliances. The results achieved by the Hanscom and Card brakes are not averaged, as their cars were withdrawn early in the trial.

The Hanscom brake, on the eighth day of the contest, made its only stop run over the course. At the No. 4 stop the distance post was passed above the maximum speed allowed, and hand brakes were consequently called for. The brake was in a very unmanageable condition, and the fact that difficulties, which appeared trivial in testing a few cars,

became insurmountable when multiplied by fifty, was never better illustrated than in this case. No driver brake was used on the engine, which, of course, materially impaired the results. After this run Mr. Hanscom withdrew his brake from the contest.

The Card Brake Company appeared on the ground with their 50 cars and engine some days after the contest had commenced. The company used the American steam brake on its engine. On the ninth day they made their first run, but before the No. 1 post was reached the brakes went on automatically, and in stopping damaged the brake rigging of six or seven cars, which necessitated side tracking for repairs. On the twelfth day another trip was made; the breakages to the gear again were considerable, showing that much had to be done before the apparatus could be successfully entered in such a contest. The owners withdrew from the contest after this run. A glance at the brake-beam pressure curves of the three leading competitors of 1887, plates VIII. and IX., noting the rapid development of power obtained by air, shows the difficulties and kind of competition the purely electric brakes have to meet. It will be difficult to get up a mechanical device winding a chain by means of friction wheels to develop power that will be as reliable and as quick as a straight pull or push on the levers actuated by air pressure. With any winding device the power has to be developed after application. With air pressure the power is stored ready to be shot off on the first application.

Plate VII. shows the average results obtained by the three remaining competitors — Eames, Carpenter, and Westinghouse — in five different classes of stops and at two speeds for each class of stop. The classes of stops are as follows:

1st. 50 empty cars, brakes applied by air.
2nd. 50 do. do. electricity.
3rd. 50 mixed cars, do. do.
4th. 50 do. do. do. with slack shoes.
5th. 50 do. do. air.

The numbers of each individual stop from which the average is compiled, the name of the brake, the distance in which the stop was made,

THE BURLINGTON BRAKE TRIALS

corrected for uniform speed, which is also given on level and grade, the time in which the brakes become fully applied and in which they were released, is also given. The weight of the train in tons of 2,000 lbs. and the percentage of that weight braked is given, and the pressures. The movement of the slideometer indicates the severity of the shock experience in the rear car; shocks above 12 inches are considered as objectionable, and likely to injure stock and many classes of freight.

Plate VII. shows the average results obtained first with 50 empty cars stopped by air, Westinghouse and Eames brakes. The stops made by the Westinghouse have been already alluded to. The shocks with the Eames brakes were considerably less than with the Westinghouse, but amounted to a maximum of 25½ inches.

The next series of stops are those made with a train of 50 empty cars, the valves being actuated by electricity. All three brakes participated in this class of stop. The results are noticeable for the complete absence of shock and for the remarkably small distance in which the Carpenter and Westinghouse trains were stopped. The release with the Carpenter train, being effected by electricity, was remarkably quick, not exceeding 1½ seconds; while the Westinghouse, released by air, averaged 36 seconds. The Eames release was in considerably less time than the Westinghouse.

The next series of tests shown in Plate VII. are those made with a train of 50 cars, 33 loaded and 17 empty. Here again the Carpenter and Westinghouse brakes showed most remarkable results; the trains weighing from 1,500 to 1,600 tons and 2,000 ft. in length, were stopped in an average of 171 to 182 ft. on a level grade at 20 miles an hour. These stops were not accompanied by any excessive sliding of wheels, and by a very small movement of the slideometer, not exceeding ¾-in. The Eames brake in these stops stopped the loaded train in a shorter distance than it stopped the empty train, showing that their method of varying leverage increasing with a loaded car produced a decidedly good effect in shortening the stop. The Carpenter and Westinghouse stops also show a slight improvement, but this was probably due to increased

pressure, and, in the case of the Westinghouse, to increased leverage. With the Eames train the pressure cannot be increased and the levers were unaltered during the trials. The Carpenter brake would probably have shown even shorter average general stops at the No. 2, 3, and 4 posts had a larger pump and larger trainpipe been used, but the size of the pipe, ¾ in., was insufficient to properly charge the reservoir at the rear end of so long a train, making four emergency stops in seven miles. This statement does not apply to the runs 1,621 to 1,624; here the Carpenter train was allowed to wait after each stop to pump up any desired pressure. It will be observed, however, that these stops are not computed in the averages on plate VII. They pertain too much to the nature of special efforts to score a record; for similar reasons the Westinghouse stops 1,823 and 1,824 are excluded from the averages on this table.

The next to last tests were made with a train of 33 loaded and 17 empty cars, with the brake shoes placed one-half inch clear of the wheels. The Carpenter brake made a fair showing, the average distance in which the train stopped at a speed of 30 miles per hour on a level was 457 ft., the wheels on the empty cars were slid on an average from 140 to 225 feet, and there was a slight shock in the rear end, never amounting to more than ¾ in. The best results were obtained with the Westinghouse brake and were very similar to those when the shoes were the ordinary distance from the wheels, and there was no shock. The stop with slack shoes was made with the two former brakes with electric application. The Eames stops, with slack shoes, were made by air, and the results are almost identical with those obtained under similar circumstances, but with the shoes the ordinary distance from the wheels; the shock was moderate, never exceeding 7¾ in., and the wheels slid about 400 ft. on the empty cars.

Old Car Train Test.

It was a matter of considerable regret that the endurance test had to be abandoned, and thereby allow opportunity to improve parts that, under an endurance test, would necessarily have remained unchanged.

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The abandonment of such a test was all the more unfortunate, as it allowed those so disposed the opportunity of arguing with some plausibility that the stops made in 1886 and 1887 at Burlington did not represent stops attainable with trains in every-day use, that they were more in the nature of scientific stops with apparatus specially fitted up for making a record and that it was quite apparent that the many parts making up the continuous system would never give similar results after a few months' service. Serious doubts were even raised as to the practicability of the leverage used on account of the sliding of the wheels, not unusual or excessive in itself, and which is apparent when we state that not a single wheel was condemned in either 1886 or 1887, at Burlington, on account of flat spots, but which was made prominent by the very nature of the tests.

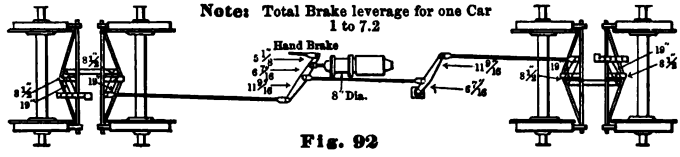


Fig. 92

Leverages of Cars in Old Car Train.

When it was suggested and decided that an old car train and engine running on the Burlington road should be tested over the course, all looked for the results with the keenest interest. This test would show the extent to which the equipment of the several competitors was especially prepared for the contest. A 25 old car train in a few days was collected and given a run over the course. If it was right to say that the brake companies' equipment had an advantage by being specially prepared for good work, so it would have been right to say that this old car train was such a one that would show the poorest possible result. Ten or twelve of the cars were taken off the Burlington shop bad-order track, where several of them had been marked for rebuilding. The shoes were in anything but good condition, some quite worn out and others with only a portion of their surface coming in contact with the wheel. The engine had but one reservoir supply-

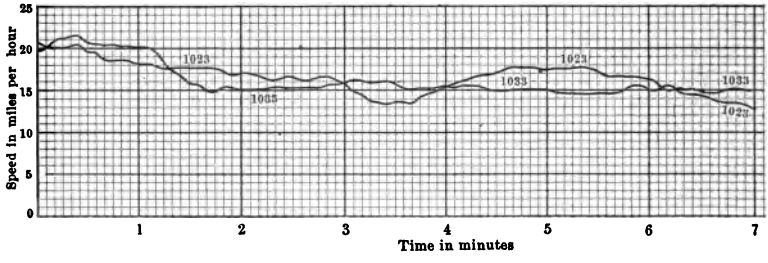
ing air to drivers and tank trucks, and only one of the tank trucks had power brakes.

The leverage under the cars was the standard of the Chicago, Burlington & Quincy, and is shown in Fig. 92.

The cars were fitted with iron brake-beams inside hung, the triples were those the Westinghouse Company sell with their freight-brake equipment and the ordinary Westinghouse engineer's valve with the Paradise extra pressure valve (owned by the Westinghouse Company), was used on the engine. Seventy pounds trainpipe pressure, the standard of the Chicago, Burlington & Quincy Railroad, was carried, so that in every respect the train represented the every-day practice of a train in regular service.

On the following page will be found a record of this run with 25 empty cars; for comparative purposes we have placed also 25 mixed

Fig. 93 **Carpenter**



car runs of the Westinghouse Company in 1886. The stops of this old car train are certainly remarkable ones.

Some allowance should be made in favor of the Westinghouse trial train, owing to the fact of its being loaded, while the old train was empty. It will be seen that, with the exception of No. 1 stop, the old car train, in so far as distance is concerned, actually made shorter stops than the trial train. While the handicapping necessary to an empty-car train competing with a mixed-car train can be determined theoretically, we would draw the attention of those considering such a calculation to the difference in the empty and mixed car stops of 1887. Attention also should be given to the pressure column, as it will be

TABLE XXIII.

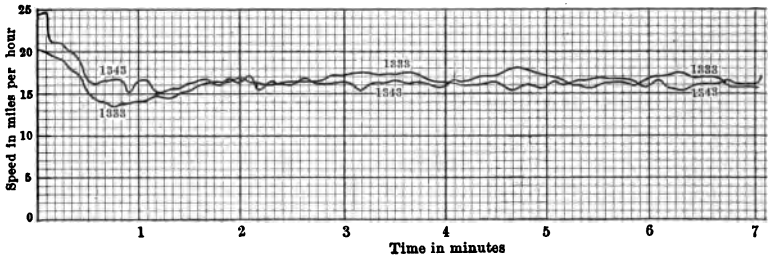
Kind of Stop.	No. of Stop.	Cars Braked and Unbraked.	Weight, Including Engine and all Cars.	Length of Stop Corrected to 20 and 40.	Actual Records.			Shock.	Remarks.
					Speed.	Distance.	Time.		
25 mixed car train, 1886	221	27	1,282,430 lbs.	275	22.1	335	14½	. . .	No slideometer used.
25 do. do.	161	27	1,282,430 lbs.	301	23.	398	18½	. . .	do. do.
25 do. do.	211	27	1,282,430 lbs.	302	21.5	349	15½	. . .	do. do.
25 empty car train, 1887	1511	27	778,000 lbs.	308	20.5	324	14½	14½	Weight of train estimated.
25 empty car train, 1887	1512	27	778,000 lbs.	770	43.	887	. . .	17⅜	Weight of train estimated.
25 mixed car train, 1886	222	27	1,282,430 lbs.	979	40.	979	25½	. . .	No slideometer used.
25 do. do.	161	27	1,282,430 lbs.	991	43.5	1,172	26½	. . .	do. do.
25 do. do.	212	27	1,282,430 lbs.	1,004	40.5	1,029	27½	. . .	do. do.
25 empty car train, 1887	1513	27	778,000 lbs.	273	21.5	313	15	16⅜	Weight of train estimated.
25 mixed car train, 1886	213	27	1,282,430 lbs.	307	21.7	361	17¼	. . .	No slideometer used.
25 do. do.	163	27	1,282,430 lbs.	317	22.4	398	18	. . .	do. do.
25 do. do.	223	27	1,282,430 lbs.	320	20.0	320	14½	. . .	do. do.
25 empty car train, 1887	1514	27	778,000 lbs.	824	43.	944	24¾	21⅝	Weight of train estimated.
25 mixed car train, 1886	164	27	1,282,430 lbs.	1,088	46.8	1,490	34¾	. . .	No slideometer used.
25 do. do.	214	27	1,282,430 lbs.	1,155	45.	1,462	34	. . .	do. do.
25 do. do.	224	27	1,282,430 lbs.	1,296	44.	1,506	35	. . .	do. do.

observed that both the Westinghouse Company and Carpenter carried higher pressures in their mixed-train stops than with the empty train.

It will be seen from this table that, with the increased pressures, the mixed loads only added to the length of the No. 1 empty stops some 50 or 60 feet. About the same figures are given at No. 3 stop. In comparing the No. 2 and No. 4 stops, it should be borne in mind the empty-train speed at these stops was 40 miles an hour, while the mixed was at 30 miles.

Making due allowance for the condition of the old car train, its records seem to point in the strongest way that the stops at Burlington

Fig. 94 **Eames**



were not in any sense show tests, but what may be expected in every-day service.

Down-Grade Run.

No greater evidence of the advance in the brake problem in one year can be had than a perusal of the down-grade diagrams of the Carpenter and Eames brakes (Figs. 93 and 94). The Eames used its electric apparatus in making this run, and maintained, practically, a uniform speed. The 1887 down-grade runs are shown by Figs. 93, 94, and 95. These diagrams are constructed on the same plan as in 1886, which is described on page 155. The distance run was somewhat shorter in 1887 than in 1886, viz., 1.926 miles instead of 2.021 miles. The apparent irregularity in the speed line is due to the foreshortening necessary in order to get so long a run in so short a compass

Table XXIV.—Westinghouse Electric, 1887.

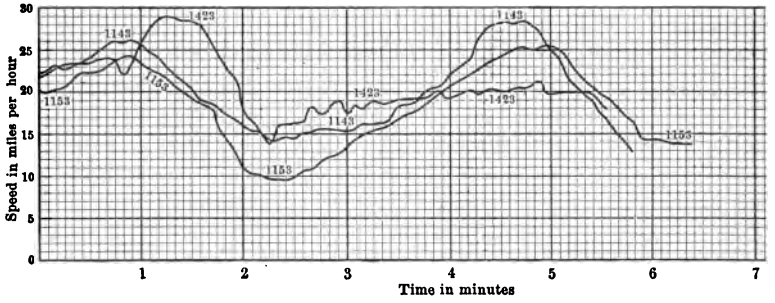
Kind of Stop.	No. of Stop.	Cars Braked and Unbraked.	Weight, Including Engine and all Cars.	Length of Stop Corrected to 20 Miles.	Speed.	Distance.	Time.	Shock.	Trainpipe Pressure on Engine Before Stop.	Remarks.
Emergency, 50, empty .	1721	50	1,661,964	130	19½	124	8¼	1″	71 lbs.	
do. do. do. .	531	51	1,731,650	138	23	183	7¾	0	71 lbs.	
do. do. do. .	611	51	1,731,650	146	21¼	165	7¼	0	75 lbs.	
do. do. mixed .	1121	52	3,282,650	174	21½	201	11¼	0	82 lbs.	
do. do. do. .	1111	52	3,282,650	187	20¾	201	11¼	0	81 lbs.	

Carpenter Electric, 1887.

Emergency, 50, empty .	751	51	1,535,226	104	23	138	7½	0	72 lbs.	
do. do. do. .	821	51	1,535,226	104	23	138	6½	0	72 lbs.	
do. do. do. .	811	51	1,535,226	112	23¼	151	6¾	0	66 lbs.	
do. do. mixed .	1621	52	2,960,335	138	20½	145	8¾	3⅛	88 lbs.	
do. do. do. .	1011	52	2,960,335	143	19½	136	9¾	¾	92 lbs.	
do. do. do. .	941	52	2,894,327	165	21½	191	10½	¼	75 lbs.	

rather than to any sudden variations in speed. The Westinghouse used its automatic air brakes, and, it will be seen, makes rather a worse showing than last year, and will not compare with its two electric competitors of 1887. In run 1423, fifteen retaining valves were set, which improved the latter part of the run, though still showing a tendency to gain too much in speed.

Fig. 95 **Westinghouse**



Break-in-two Tests.

The break-in-two tests are shown in the following table, and were participated in by the Eames, the Carpenter, and the Westinghouse brakes, the Hanscom and the Card having succumbed in the earlier test. Nothing noticeable occurred. Wedges were placed in the Carpenter train to wedge out the free link slack, inasmuch as with a break-in-two its brakes were applied by air in place of electricity. The train was parted in the same manner as in 1886, but with a 50 empty car train in place of a 25 mixed car train, and the parting was made in the forward third of the train in place of in the middle. This change was made to develop any tendency of the rear trains failing to stop and thereby colliding with the forward section. The stops were all successively made. In the first break-in-two with the Carpenter the electric connection was broken, which prevented the engineer from throwing brakes off the front end, a claim made by the Carpenter in common with the Eames.

TABLE XXV.—1887—BRAKE-IN-TWO TESTS.

Stop Number.	Name of Brake.	Train.	Trainpipe Pressure. Engine.	Trainpipe Pressure. Rear Car.	Speed in Miles at Parting of Train.	Distance Between Sections During and at Stop.		Movement of Slide-ometer, Rear Car, in Inches.	Miscellaneous.	
831	Carpenter . .	50 empty cars, engine, dynamometer and way car	69	58	21½	At stop	8′7″	0	The hose in parting broke electric coupling, preventing release on front section.	Train parted between 15th and 16th cars
832	do. . .	50 empty cars, engine, dynamometer and way car	64	53	29½	do.	400′9″	0	Engine released on front portion and pulled sections apart.	
411	Eames . . .	50 empty cars, engine, dynamometer and way car .	10¼	9½	21	During stop	8′0″	1¾	Train recoupled with slight shock	Train parted between 17th and 18th cars
412	do. . . .	49 empty cars, engine, dynamometer and way car.	10	9	30½	do.	10′0″	5½	do. do.	
421	do. . . .	48 empty cars, engine, dynamometer and way car .	9½	8¾	21	do.	3′0″	11¼	do. do.	
422	do. . . .	48 empty cars, engine, dynamometer and way car .	9⅝	8¾	29½	do.	17′0″	⅝ 2½	do. do.	
431	Westinghouse	49 empty cars, engine, dynamometer and way car .	70	66	25	At stop	17′0″	31⅜	Train separated 6′, came together again and then parted to 18′.	Train parted between 15th and 16th cars
432	do.	49 empty cars, engine, dynamometer and way car	77	70	28	do.	18′0″	39 $\frac{3}{16}$		
441	do.	49 empty cars, engine, dynamometer and way car	74	67	21	During stop At stop	30′0″ 12′0″	22¼		
442	do.	49 empty cars, engine, dynamometer and way car	74	69½	28	During stop At stop	30′0″ 19′0″	21¾		

Middle Car Diagram.

The most interesting and instructive records obtained during the trials were the middle car diagrams. We reproduce on plates VIII. and IX., and Figs. 96 to 99, a few typical stops of the principal competitors. A description of the reading of these diagrams will be found on page 135. In examining these diagrams, particular attention is directed to the fact that the vertical scale of the pressure curve of each competitor is different. This difference was an unavoidable one, caused by the variations in truck leverages, cylinder leverages, and, in some cases, the bell-crank connection to the recording apparatus.

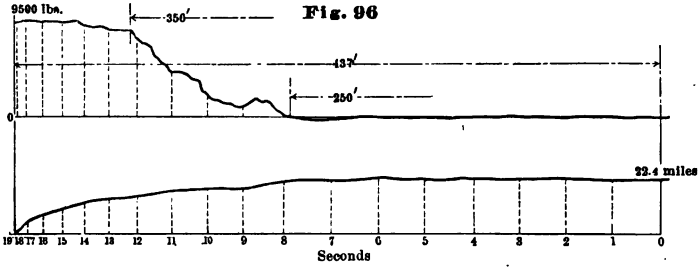
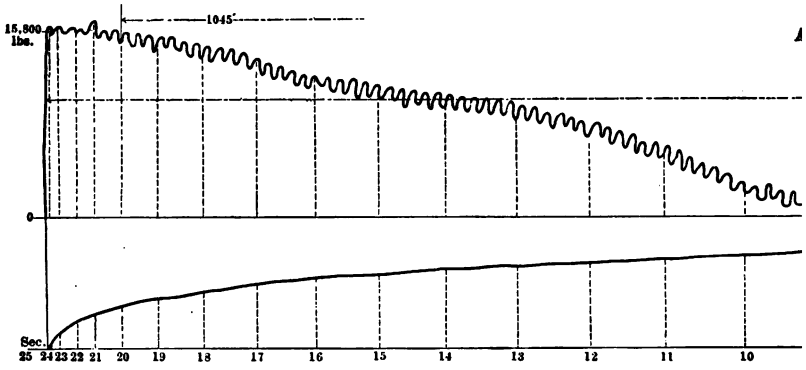


Fig. 96

Middle Car Diagram, Eames, 1886.

The scale is also given on each sheet, so that there need be no misapprehension as to the relative value of the vertical stress line. The faults incident to slow application have already been referred to. The extent to which electric application has improved this is clearly seen by comparing the Westinghouse and the Eames 1887 automatic stops with their 1887 electric stops. Having established the importance of instantaneous application on each car, it next becomes important to get maximum pressure of shoes against the wheels in the shortest possible time. If we look at the Eames diagrams, Figs. 96 and 97, it will be observed that the vacuum stops of 1886 and 1887 show but little difference in commencement of application :

	Stop No.	Speed.	Brakes begin to apply on 25th car.	No. of seconds elapsed.	Stop.
1886 . .	521	22.4	250 feet.	8	437
1887 . .	711	21.75	213 feet.	7⅓	364



M. C. B. Brake Tests, 1886 & 1887

MIDDLE CAR DIAGRAMS.

Showing

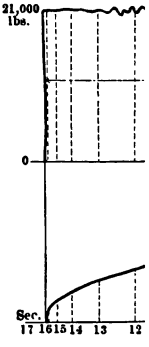
Pressure on all Brake Shoes of one Car; Speed of Train, Distance Run after Application of Brakes and Length of Time Intervening between Application of Brakes on the Engine and on the Middle Car.

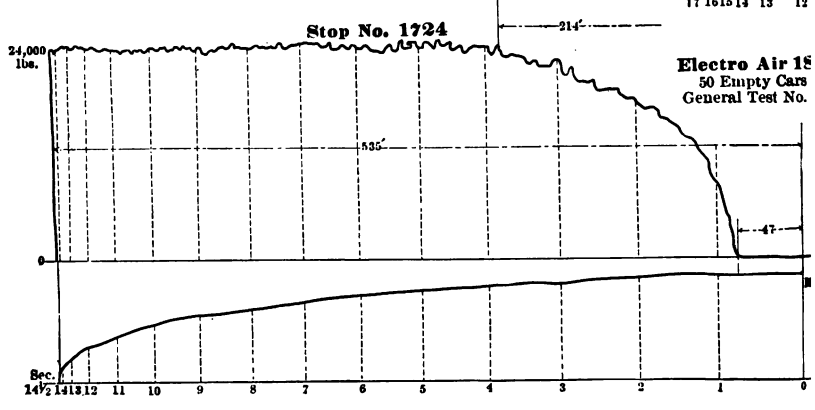
Westinghouse Air Brake

Scale for Speed in Miles

5 0 10 20 30 40 50

Note: Dotted vertical lines show time in Seconds.

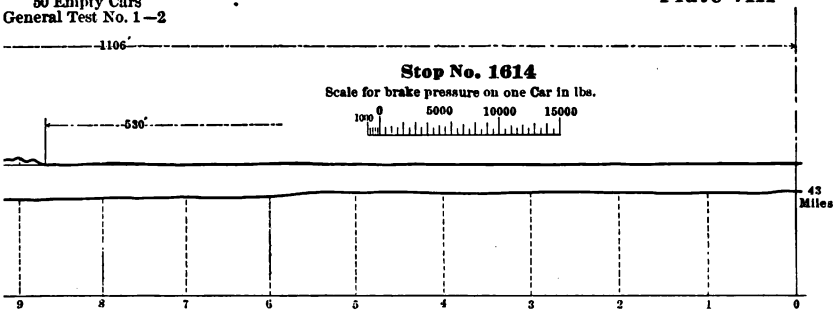


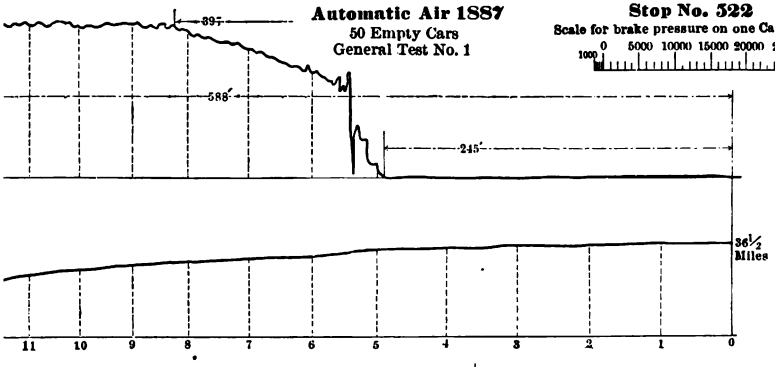


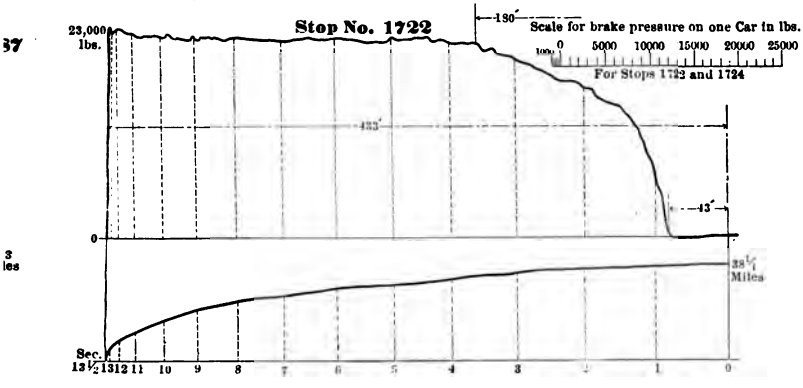
Electro Air 18
50 Empty Cars
General Test No.

utomatic Air 1886
50 Empty Cars
General Test No. 1—2

Plate VIII







Air Brake Tests

THE BURLINGTON BRAKE TRIALS

The stop, however, is much shorter; this is due to the greater pressure against the wheels obtained in 1887, viz.: 24,000 lbs. as against 9,500 lbs. The development of power with the Electric Eames shows the same exceedingly slow pressure curve, which clearly accounts for its not doing the work of its competitors, the Westinghouse and the Carpenter.

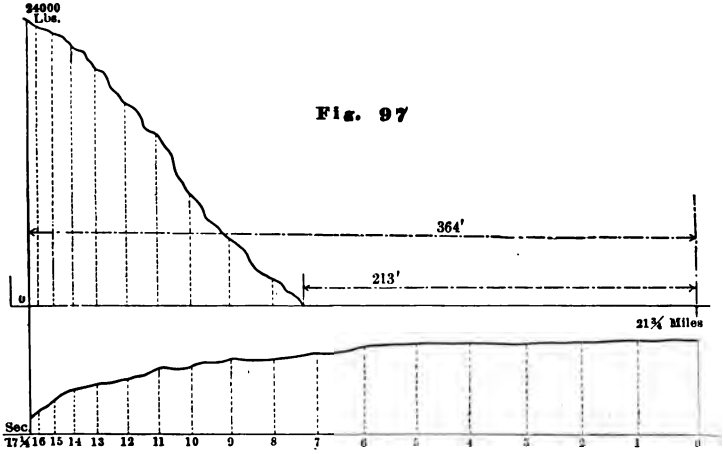


Fig. 97

Middle Car Diagram, Eames, 1887.

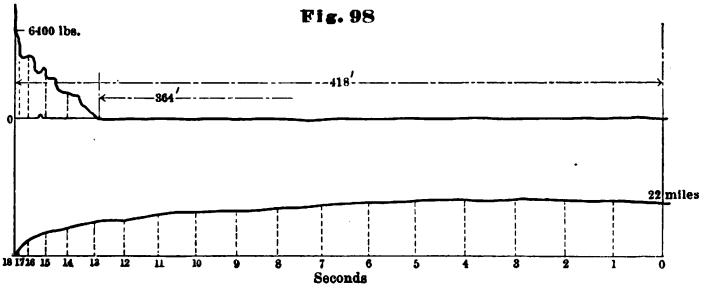
An examination of the Westinghouse diagrams, Figs. 98 and 99, is equally interesting. A marked improvement is shown in the automatic brake of 1887:

	Stop No.	Speed.	Brakes begin to apply on 25th car.	No. of seconds elapsed.	Stop.
1886 . .	1,611	22	364 feet.	13	418
1887 . .	511	19.25	110 feet.	4.25	215

The work of the improved triple valve becomes quite apparent here, but the stress line also shows that the importance of a rapid development of power has been observed. No clearer demonstration of the extent to which the brake company has realized this can be had than by a comparison of the stress curves of stop 1,614 of 1886 and stop 1,724 of 1887, plate VIII. The curves with the electric application

of the Westinghouse are the same as their automatic application, the shorter stops being due solely to quicker application. Before leaving this subject it is instructive to note that in stop 1,611 of 1886 no development of power against the wheels is shown in this 25th car until 13 seconds have passed. If we now refer to the journal of tests for 1886, we will find under its proper column that the time the "brakes begin to apply" on the 50th car is about 8 seconds; that is to say, the air began to go into the cylinder of the 50th car in 8 seconds from the stop signal, and it developed its maximum cylinder pressure in 11 seconds. The air from the auxiliary reservoir of the 25th car must have gone into its cylinder earlier than on the 50th car, and yet no

Fig. 98



Middle Car Diagram, Westinghouse, 1886.

pressure is shown against the wheels until 13 seconds have elapsed. Clearly, then, the air, which first goes into the cylinder, has a function to perform before it can develop pressure against the wheels. Piston frictional resistance has to be overcome, cylinder springs compressed, slack in foundation gear has to be taken up, brake beams stretched taut, and the time necessary to do this in the 1886 tests was stretched out to unreasonable limits by the slow development of power. The action of the triples would also have some influence. A marked improvement in this respect appears in the 1887 tests.

The Carpenter diagrams (see Plate IX.) show very clearly how the stops were effected. At both the 20 and 40 miles speeds the maximum brake-beam pressure was reached generally in about 2 seconds

THE BURLINGTON BRAKE TRIALS

from the commencement of the application, and as the application is almost simultaneous with the stop signal, the stop is correspondingly good. The accurately fitted foundation gear of this brake resulted in a very short piston travel, which doubtless had much to do with the excellence of the stress curve. It is a question, however,

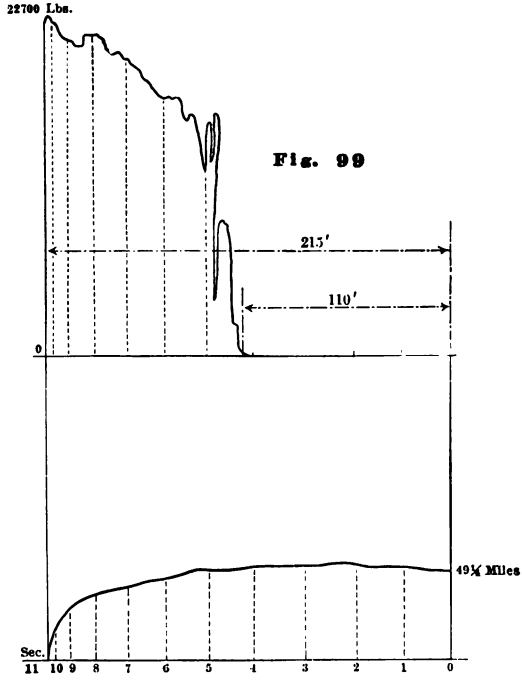


Fig. 99

Middle Car Diagram, Westinghouse, 1887.

whether even this rapid development of stress application might not be bettered by a quicker admission from the auxiliary reservoir to the cylinder. By reference to Plate IX., of the American brake, it will be observed the maximum application is reached instantaneously with the application itself. While such an application pertains doubtless too much to a

hammer blow, the endeavor should be to reach the maximum stress line in one second's time, which would bring about shorter stops than those shown with the Carpenter brake.

While the Committee were not prepared to make any definite recommendation at that time as to what freight train brake should be generally adopted, the information derived from these recent tests pointed to two conclusions:

First—That the best type of brake for long freight trains is one operated by air and in which the valves are actuated by electricity.

Second—That this type of brake possesses four distinct advantages:

(*a*) It stops the train in the shortest possible distance.

(*b*) It abolishes shocks and their attending damage to equipment.

(*c*) It releases instantaneously.

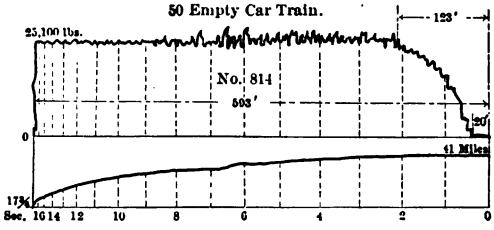
(*d*) It can be graduated perfectly.

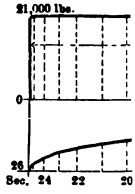
The further question, as to whether electricity was a sufficiently reliable element to use in freight train service, was one that could only be determined by experiment; but the benefits derived from electricity were so manifest that the experiment was well worth trying. In view of the foregoing and of the improvements that were being made, the Committee recommended that the subject of Automatic Freight Train Brakes be continued for further investigation.

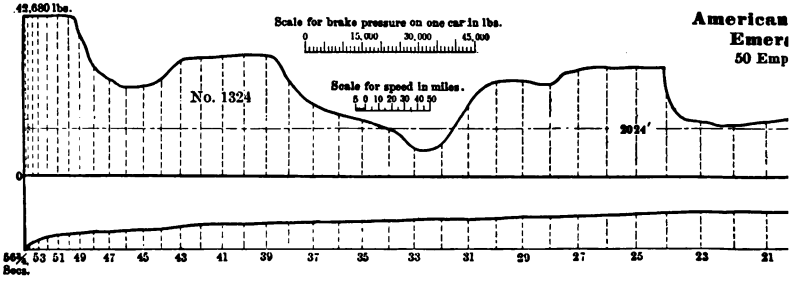
M. C. B. Brake T
MIDDLE CAI

Showing pressure on all brake shoes of one car, spe and length of time intervening between appli

Carpenter Electric Air Brake
Emergency Stop
50 Empty Car Train.







American
Emer
50 Emp

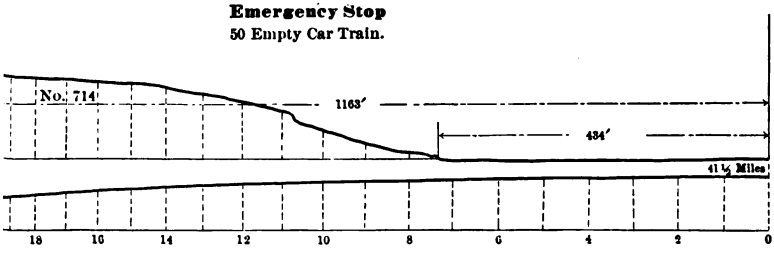
Plate IX

st, 1886 and 1887.

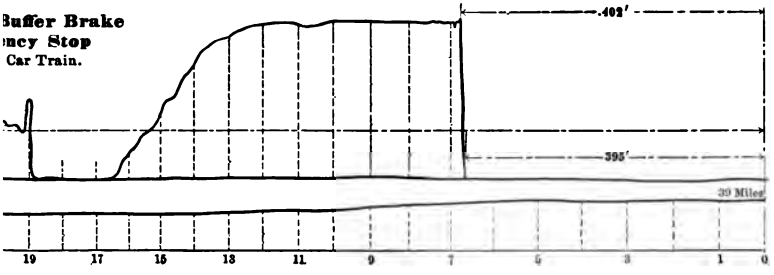
DIAGRAMS.

l of train; distance run after application of brakes;
ition of brakes to engine and to middle car.

Eames Automatic Vacuum Brake
Emergency Stop
50 Empty Car Train.



Buffer Brake
ncy Stop
Car Train.



WESTINGHOUSE FREIGHT TRAIN TEST.

As stated in the conclusion of the 1887 report of the Air Brake Committee to the Master Car Builders' Association, the various competing Brake Companies were loath to accept the results of the Burlington trials as final.

It is true that the buffer brakes practically went out of existence after these trials, but the companies furnishing continuous brakes, although disturbed and chagrined at the very discouraging results of the tests, were still confident that they were following the right track and determined to develop their devices so as to overcome the shocks which were so dangerously manifest all during the Burlington trials.

The Westinghouse Company, in particular, was not willing to let the results so obtained stand uncorrected, and Mr. George Westinghouse,— who is in reality the "Father of Air Brakes" in that his invention in this line was the first practical device of its kind, and whose determination and perseverance has brought about the whole art of air breaking,— was thoroughly convinced that his invention could be made to control a 50-car train without the aid of an electrical attachment. Although the results of the trials just finished pointed with apparent certainty to the conclusion that such attachment was indispensable, Mr. Westinghouse at once set about making certain changes in his apparatus which would quicken the serial application of the brake to such an extent that the application on the last car would occur before the slack could run in. These changes consisted of enlarging the trainpipe from one inch to one and a quarter inches; and also in making changes in the triple valve whereby the quick-action feature was greatly increased through larger passages and more sensitive valves. In this manner the time of application through a 50-car train was reduced from six seconds to less than three. This was demonstrated upon the same train which was used in the Burlington tests in 1887, which was made up of 50 cars 38 ft. 4 in. long, of 60,000 lbs. capacity; the total length of the train was 1,900 feet and the total weight 2,000,000 lbs. After the above mentioned demonstration convinced the Westinghouse Air Brake Co. that the problem had been solved, this train was sent on a

WESTINGHOUSE FREIGHT TRAIN TESTS

tour through some of the principal cities of the country in each of which it gave two series of trials, which were attended by many hundreds of railway managers, press representatives, prominent citizens, and professors and students of technical schools. These trials were made during October, November, and December of the same year as the last Burlington trial — 1887. The following table gives the general results of the trials which were in most of the cities divided into ten different tests. The results were widely published in all the technical papers. One engine was used in all of these tests, except those at St. Paul, where two were used. In the table, all fractions of miles and seconds have been omitted.

Description of Tests.

1. Emergency stop, train running 20 miles an hour.
2. Emergency stop, train running 40 miles an hour.
3. Applying brakes while train is standing still, to show quickness of application.
4. Emergency stop, with passengers aboard; speed, 40 miles per hour.
5. Service stop, and time of release. Showing the kind of stop made when a sudden stop is not necessary, and how promptly the brakes can be released.
6. Hand-brake stop, made at 20 miles an hour, with five brakemen at their posts (at Buffalo there were seven brakemen).
7. Breaking train in two.

All the above stops were made with the braking power so low that it would not slide the wheels of empty cars in regular service. By using greater power, quicker stops could be made, but there would be more or less sliding of wheels, and it was not thought that the advantage gained would be enough to make up for the damage done in freight service.

8. Train running 20 miles an hour; the brake leverage having been increased to give the quickest stop possible.
9. Train running 40 miles an hour; leverage as in No. 8.

SUMMARY OF RESULTS OF TESTS, WITH FIFTY-CAR TRAIN, IN OCTOBER, NOVEMBER, AND DECEMBER, 1887.

Place of Test.	Down Grades, Feet per Mile.	First.			Second.			Fourth.			Sixth.			Seventh.		Eighth.			Ninth.			Tenth.		
		Speed, Miles.	Distance, Feet.	Time, Seconds.	Speed, Miles.	Distance, Feet.	Time, Seconds.	Speed, Miles.	Distance, Feet.	Time, Seconds.	Speed, Miles.	Distance, Feet.	Time, Seconds.	Speed, Miles.	Feet, distance apart.	Speed, Miles.	Distance, Feet.	Time, Seconds.	Speed, Miles.	Distance, Feet.	Time, Seconds.	Speed, Miles.	Distance, Feet.	Time, Seconds.
St. Paul	13.6	19	172	7	36	490	15	20 37	200 583	. .	.	. .	.	25	100	20	109	.	37	327	. .	.	. . .	. .
Chicago	Level, head wind.	22	184	10	37	480	15	20 34	162 470	11 15	19	1,200	62	20	59	20	120	6	33	272	11	.	. . .	. .
St. Louis	52.8	20	176	11	36	507	18	35	502	17	21	2,115	128	23	61	20	109	6	38	377	11	.	. . .	. .
Cincinnati	50.0	25	284	12	35	542	17	37	573	17	21	1,925	75	22	32	20	102	6	41	425	12	.	. . .	. .
Cleveland	40.0	26	265	12	43	718	20	38	636	17	23	1,686	65	25	45	20	96	6	40	375	11	43	767	22*
Buffalo	32.20	21	214	12	40	679	19	39	648	19	20	1,000	48	.	59	20	93	6	40	414	13	.	. . .	. .
Albany	35.0	20	158	10	36	560	18	37	580	19	20	1,342	60	.	180	19	78	5	40	358	12	.	. . .	. .
Boston	40.0	19	123	10	32	406	16	34	483	17	21	1,035	54	22	62	20	111	8	.	.	.	38	319 547	12 17
New York	53.0	23	203	12	41	674	20	41	672	20	21	2,137	85	.	43	22	91	6	.	.	.	45	495 1,204	13 27
Philadelphia	44.0	23	264	14	36	593	19	36	579	18	18	1,889	75	22	35	20	87	6	.	.	.	49	647 932	19 23
Washington	52.0	19	159	10	42	694	21	42	718	21	20	1,643	67	23	58	21	81	6	40	359	11	.	. . .	. .
Pittsburg	47.0	20	194	11	40	649	21	40	673	20	20	1,720	72	.	. .	20	95	6	.	.	. .	45	494 890	14

* Passenger train only. Compare with freight train in Test No. 9.

THIRD TEST.— In all cases the brakes went fully on within two seconds. FIFTH TEST.— The brakes were released in all cases in four seconds, and at Boston in three seconds.

WESTINGHOUSE FREIGHT TRAIN TESTS

10. A train of 20 freight cars and a train of 12 ordinary passenger coaches were run alongside of each other, on parallel tracks, and the brakes applied at the same time. This test showed the relative stopping power of the old and the new brakes.

As a result of this train's now famous tour, the Committee of the M. C. B. Association on Freight Train Brakes reported to the meeting of that Association held at Alexandria Bay, N. Y., June 12th, 13th, and 14th, 1888, as follows:

"In our report to the convention last year the main conclusion we arrived at was that the best type of brake for freight service was one operated by air, and in which the valves were actuated by electricity. Since that time your Committee has not made any further trial of brakes, but the aspect of the question has been much changed by the remarkable results achieved in non-official trials which have taken place in various parts of the country, and have been witnessed by many of the members of this Association. These trials show that there is now a brake in the market which can be relied on as efficient in any condition of freight service.

"The present position of the freight train brake is briefly as follows:

"First — Brakes can be, practically speaking, simultaneously applied without electricity throughout a train of 50 freight cars.

"Second — Other inventors are working at the problem of making an air brake which will be rapid in action and suitable for service on freight trains. We also understand that inventors are working at buffer and electric friction brakes, but we have no reason to hope that brakes on these principles can successfully compete with air brakes.

"In view of these conditions, your Committee does not recommend the adoption of any particular brake, but considers that a freight-train brake should fulfill the following conditions:

"First — It shall work with air of 70 lbs. pressure. A reduction of 8 lbs. shall set the brakes lightly, and a restoration of pressure shall release the brakes.

"Second — It shall work without shock on a train of 50 cars.

Air Brake Tests

WESTINGHOUSE FREIGHT TRAIN TESTS

"Third — It shall stop a train of 50 empty freight cars when running at 20 miles per hour within 200 feet on the level.

"Fourth — When tried on a train of 50 cars it shall maintain an even speed of fifteen miles an hour down a grade of 53 ft. per mile without variation of more than five miles per hour above or below that speed at any time during the descent.

"Fifth — The brake shall be capable of being applied, released, and graduated on the whole train by the engineer, or without any assistance from brakemen or conductor.

"Sixth — The hose coupling shall couple with the present Westinghouse coupling.

"We recommend that all freight cars fitted with such a brake shall be marked 'Air Brakes' on each side of the car, near the top. The Committee further recommends the use of iron or steel brake-beams, and that the subject of the best form and proportion of brake gear and the selection of a standard solid brake shoe for use with metallic brake-beams should be entrusted to a committee appointed for the purpose."

(Signed.) G. W. Rhodes,
George Hackney,
John S. Lentz,
D. H. Neale.

THE KARNER TESTS.

In the early part of September, 1892, comparative tests of quick-action brakes were made at Karner Station on the New York Central & Hudson River R. R. One hundred standard 60,000 lbs. capacity box-cars, built by the Buffalo Manufacturing Co., and fitted with the Gould Coupler, were prepared for two trains. One train of fifty cars was equipped with the New York Air Brake reservoirs, eight-inch cylinders and No. 2 triples. The other train of fifty cars was equipped with the Westinghouse Air Brake reservoirs, eight-inch cylinders and triples with their standard springs of .073 in. in diameter.

The trainpipe was 1¼ in. diameter, with Westinghouse hose connections and cocks for both trains.

All of the cars were reweighed with the exception of three of the Westinghouse train which did not arrive in time to be weighed. The loss from the weight marked on the cars averaged from 850 to 1,000 lbs.

The leverages were such that the ratio of the piston pressure to the braking pressure on the wheels, figures 1 to 6½. With 60 lbs. of air in the cylinder, the pressure on the wheels figured 19,500 lbs.—about 70 per cent. of the weight of the empty car. The loss of pressure from release springs or friction of the connections was not considered.

The trucks were the heavy Buchanan diamond pattern, hollow iron brake-beams with inside hung cast-iron shoes. The shoes were 13½ in. long by 3¼ in. wide, equal to about 44 sq. in. for 60 lbs. of air in cylinder.

The journals were 4¼ in. x 8 in.; wheels 33 in. in diameter, weight 560 lbs.

The cars had been in service running between Buffalo and New York and Buffalo and Boston for nearly three months, until collected at Karner for the trials, the shoes being well worn to the wheels.

A few of the reservoirs were filled with water to ascertain their cubical contents. The older Westinghouse cylinders ranged from 1,610 1,618 cu. in., the recent ones cast at Wilmerding and on the cars of the Westinghouse train, ranged from 1,620 to 1,630 cu. in. The New

THE KARNER TRIAL TRAINS.

THE KARNER TESTS

York reservoirs tested, ranged from 1,632 to 1,640 cu. in. The trainpipe and hose for each car averaged 640 cu. in.

Three cars of each kind of brakes were piped with ¼-in. pipe for a gauge each, on the trainpipe, reservoir, and cylinder; also with connections so that pipes could be run to the indicators on the recording mechanism in a special car called the Dynagraph car.

Each company sent eight gauges for its respective equipment; the ninth required was one fitted with electric contacts for the cylinder of the 25th car, and was to be used for both trains. The gauges of both brake companies were of the same manufacture and were corrected by comparing them with the test gauge at the West Albany shops.

Mogul locomotives with 6 drivers 64 in. in diameter, pony-truck, cylinders 19 in. x 26 in., carrying 140 lbs. of steam, were fitted with tripping devices shown in Fig. 100, for automatically applying the air, by tripping blocks placed in the tracks directly under the signal banner for shutting off steam.

To make the tripping device upon the locomotive for automatically applying the air, a tee was inserted in the trainpipe near the engineer's valve, and from it a pipe was carried down underneath the cab to within 18 in. of the track; a plug cock being fitted in this pipe near the engineer's valve, so it could be opened or closed by the engineer in case any accident should occur to the pipe. Below the cab, in the lower part of this same pipe, another plug cock was arranged with a spring attached to the handle, so the tension of the spring would hold it open. A bracket from the engine frame carried the tripping lever, the upper end forming a hook which held the handle of the cock when the latter was closed. The lower end of the tripping lever was about 2 in. above the top of the rail.

To the lower end of the tripping device pipe a union was attached in which the diaphragms could be placed for those tests requiring their use. Precaution was taken to have the tripping lever and its bracket entirely independent of the brake gear below the cab, so in case any accident occurred to it, it would not be likely to interfere with the working of the air in the proper mechanism.

Each engine was equipped with this special device. The locomotives were just out of the repair shops. One locomotive was also piped for the use of the small diaphragms required to test the sensitiveness of the emergency valve.

A Boyer speed recorder was also put in the same engine to assist the engineer in running at the desired speed; the engineer of the train on the adjacent track to run at the same speed by keeping abreast of the other.

The devices for determining the actual speed of each train were electrical trips placed eighty-eight feet apart in each track, as described later.

Each locomotive was equipped with the usual Westinghouse brake mechanism; the pump being 8 in. in diameter, and the main reservoir 26½ in. by 34 in., having a capacity of 16,500 cu. in.

To ascertain the intervals of time from the opening of the engineer's valve to the application of the air on the first car and on the fiftieth car, the recording mechanism of the Dynagraph car was fitted up with two pressure indicators and a battery of electro-magnetic pens.

Two of the electro-magnetic pens were connected to a chronometer for making the chronograph records upon the moving paper. One pen was connected to the engineer's valve on the locomotive and another pen to a telegraph key, so that any other signals desired might be recorded. A small electric motor run by a storage battery was geared to shafting, driving the feed rolls and winding drums of the recording mechanism, and a circuit closer enabled the mechanism to be run when desired. The paper was 20 in. wide and usually ran at a speed of 1.4 in. of paper per second.

A tee below each indicator connected two branch pipes having cocks, one branch leading directly to the trainpipe of its respective car; the other branch by a tee was further subdivided, one branch connecting with the reservoir and the other with the cylinder of the same car. Connections with the first and fiftieth cars of the train with the recording instrument were thus provided for during the standing tests, described later.

FIG. 100.—TRIPPING DEVICE USED AT KARNER TRIALS.

Air Brake Tests

THE KARNER TESTS

The 50-cars were divided into two sections of 25 cars each and placed on parallel tracks, with one track intervening for convenience of observation. The twenty-fifth and twenty-sixth cars were connected by 1¼ in. pipe 27 ft. in length, and 4 lengths of hose connections. The first, twenty-fifth, and fiftieth cars of each train were provided with gauges. The first and fiftieth cars were placed nearly opposite on the parallel tracks; the first car was attached to the locomotive and the fiftieth car was attached to the Dynagraph car, and pipe connections from the first and fiftieth cars were made to the indicators above mentioned. Similar diagrams had not before been obtained, and formed a fitting supplement to the invaluable Burlington tests, which were the inception of automatic freight brakes for long and heavy trains. The present diagrams not only showed the progress which had been made since those trials, but confirmed, in a comprehensive way, that progress must follow closely along the lines there well defined.

Previous to the standing tests on September 6th and 7th, the trains were charged with air, the trainpipe tightened, the leaks in the gaskets or sand holes of reservoirs, cylinders, or triples were noted but not repaired. None of the tripple valves were taken down, excepting one from each brake, and these were found quite free from grit and well lubricated for having had three months service.

The engineers and crews were from the regular freight service, and while familiar with handling 25-car trains with air, this was their first experience with 50-car trains equipped with air brakes, and both engineers expressed surprise at the tightness of the train line in comparison with shorter trains.

The following programme stating the general character and number of the tests was printed for the guidance of employees and observers:

PROGRAMME — NEW YORK CENTRAL & HUDSON RIVER RAILROAD CO.

Trials of the Westinghouse Air Brakes and the New York Air Brakes for Freight Trains, at Karner, Sept. 8, 9, and 10, 1892.

Tests to commence at 9.00 A. M. each day, and to be practically the same as those recommended by the Committee on Air Brakes of the M. C. B. Association.

THE KARNER TESTS

Air Brake Tests

Condition of Tests.

50-car trains.

Trainpipe pressure, 70 lbs.

Piston travel, 5 in. to 7 in.

Standing Tests.

Locomotive and Dynagraph car, to be side by side on parallel tracks.

25 cars attached to the locomotive, and 25 to the Dynagraph car.

The air hose of the 25th and 26th connected.

The first and fiftieth cars connected by air pipes to the instruments on the Dynagraph car.

Running Tests.

The trains of 50 cars will be placed on parallel tracks and run side by side at same speed. Locomotives shut off at signal-post. Air automatically applied by tripping block.

Schedule of Tests. Testing Trainpipe.

1. Trainpipe charged with 70 lbs. of air. All brakes cut out, pump shut off. Record of pressure to be taken at the end of five minutes.

2. Trainpipe recharged to 70 lbs. Service application to see time required for reduction of trainpipe pressure from first to fiftieth car.

3. All brakes cut in. Time of reduction in pressure of trainpipe from first to fiftieth car. Service application and release. (*Note—Service application to be 20 lbs. reduction in trainpipe.*)

4. Same as No. 3, except emergency application. (*Note—Handle of engineer's valve in emergency notch one second—for emergency application.*)

5. Time of development of pressure in cylinders from first to fiftieth car. Service application and release.

6. Same as No. 5. Emergency application and release. Repeated three times.

7. Time of development of pressure in cylinders, the fifth, sixth, and seventh cars cut out. Emergency application and release. Repeated three times.

THE KARNER TESTS

8. (Special and optional.) Same as No. 7, except the fifth to the tenth car inclusive cut out.

Graduation Tests.

9. A reduction of 8 lbs. in the trainpipe pressure to be made; then at one-minute intervals, further reduction of 4 to 6 lbs. to be made until reservoirs and cylinders are equalized. Repeated twice.

10. Service application, 15 lbs., to be admitted into cylinders, pressure noted then at the fifth, tenth, and fifteenth minutes.

11. Same as No. 10, except all the air to be exhausted from trainpipe by emergency applications.

Release Test.

(Boiler Pressure, 160 Lbs.)

12. 70 lbs. in trainpipe, all the air will be discharged by an emergency application. A pressure of 90 lbs. will then be maintained against a diaphragm 1/8 in. thick, perforated with $\frac{3}{32}$-in. hole, and a record taken of all brakes which release in thirty minutes.

13. Test to determine the sensitiveness of the emergency valve. The first and fiftieth car will be cut from the train and hose connected; 70 lbs. trainpipe pressure will then be discharged through a diaphragm perforated with $\frac{5}{32}$-in. hole. Each car to be tested singly, if desired.

14. Test to determine time of charging one auxiliary reservoir and trainpipe. Note time of changing reservoir to 70 lbs.

RECORD OF TESTS.

TEST No. 1.—In testing the trainpipes before the tests proper, each train only lost a pound in five minutes.

TEST No. 2.—Brakes cut out. Time required for reduction of trainpipe pressure from first to fiftieth car. The engineer placed the handle of the brake valve in the service notch for three and a half seconds and reduced the trainpipe pressure 20 lbs. by gauge.

The equalizing valve rendered the action much slower, discharging air for several seconds after he had placed the valve upon lap, preventing an emergency action of the triple valves.

For these 50-car trains, 1,940 feet long, the air head in the standing tests was 5¼ lbs. The constant head was not observed until all the tables were compared, the diagrams were then re-examined and the time of the constant found to be practically the same in each train. The wave of air in the release from the high reservoir pressure traveled from the first to the fiftieth car in 6 to 10 seconds; some diagrams only showed from 3 to 4 seconds.

TEST NO. 2.—TABLE XXVI.—NEW YORK AIR BRAKE TRAINPIPE.

Pressure in Pounds, Time Intervals in Seconds.

Seconds	0	6½	19	25½	40
First Car	69.30	63.00	57.75	54.60	52.50
Fiftieth Car	69.30	68.25	63.00	59.85	55.70
Difference	0.00	5.25	5.25	5.25	2.60

WESTINGHOUSE BRAKE TRAINPIPE.

Pressure in Pounds, Time Intervals in Seconds.

Seconds	0	8	18	28	38	46	50	60
						Released.		
First Car . .	70.35	63.00	58.80	54.60	52.50	52.50	67.60	66.15
Fiftieth Car .	70.35	68.25	64.05	58.80	55.65	54.60	54.60	59.85
Difference . .	0.00	5.25	5.25	4.20	3.15	2.10	3.00	6.30

TEST NO. 3.—All brakes cut in. Time application of the pressure of the trainpipe from the first to the fiftieth cars, service application and release. In the tests of both trains, 1 to 3 seconds more time was required before a reduction was effected in the fiftieth car than in test No. 2. This discrepancy was due to the pressure being higher in the first car than the fiftieth—a flow of air still going to the latter

THE KARNER TESTS

car—and the increase of trainpipe volume from cut-out cock to triple, to be reduced.

TEST No. 3.—TABLE XXVII.—NEW YORK AIR BRAKE TRAIN.

Pressure in Pounds, Time Intervals in Seconds.

Seconds	0	11	21½	36½	48½	55½	65
First Car	70.35	61.95	57.75	52.50	Released. 52.30	63.00	. . .
Fiftieth Car	68.25	68.25	63.00	57.75	54.60	. . .	55.10
Difference	2.10	7.30	5.75	5.25	2.10	. . .	. . .

WESTINGHOUSE AIR BRAKE TRAIN.

Pressure in Pounds, Time Intervals in Seconds.

Seconds . .	0	9	19	29	39	49	59	69	79	89	99
First Car . .	70.35	63.00	58.80	54.60	52.50	51.45	Released 50.40	63.00	61.40	60.90	60.90
Fiftieth Car .	69.30	69.30	64.05	59.85	55.65	53.55	52.50	54.60	57.75	57.75	58.80
Difference. .	+ 1.05	6.30	6.25	5.25	3.15	2.10	2.10	8.40	3.65	3.25	2.10

In the New York train one car did not fully apply.

EMERGENCY APPLICATION.

TEST No. 4.—NEW YORK AIR BRAKE TRAIN.

Train line in first car 70.4 lbs., fiftieth car 69.8 lbs.

In 0.16 seconds from movement of engineer's valve the pressure commenced to fall in the first car, and in 1.8 seconds it was down to 37.8 lbs.

In 3.31 seconds the pressure commenced to fall in the fiftieth car and in 0.17 of a second, or 3.32 seconds from the first car, was down to 48.3 lbs.; first car fell to 37.8 lbs., then rose to 47.3 lbs. in 3.64 seconds.

The release was not ordered until 38 seconds after the application,

first car reading 47.3 lbs., and in 6 seconds first car read 62 lbs.; in 88 seconds from release, trainpipe pressure read in first and fiftieth cars 63 lbs.

TEST No. 4.—WESTINGHOUSE AIR BRAKE TRAIN.

Trainpipe pressure in first car 69.3 lbs., and fiftieth car 68.3 lbs.; in 0.15 of a second after the movement of the engineer's valve the pressure began to fall in the first car and in 1.81 seconds was down to 38.85 lbs. In 2.71 seconds the pressure commenced to fall in the fiftieth car, and in 2.86 seconds, or 2.71 seconds from the first car, was down to 51.45 lbs. The brakes were released in 18 seconds, the fiftieth car releasing in 4.3 seconds later.

TEST No. 5.—TABLE XXVIII.—NEW YORK AIR BRAKE TRAIN.

See Diagram, Plates Nos. X. and XI.

In .8 of a second from the movement of engineer's valve pressure commenced in the first car.

Pressure in Pounds, Time Intervals in Seconds.

Seconds	6.8	9	13	20	30	40	50	60	Released.
First Car	4.7	. . .	16.8	24.2	34.6	37.8	41.5	42.	75 Sec.
Fiftieth Car	0.0	3.1	5.65	18.9	28.4	34.7	37.8	34.7	81 do.

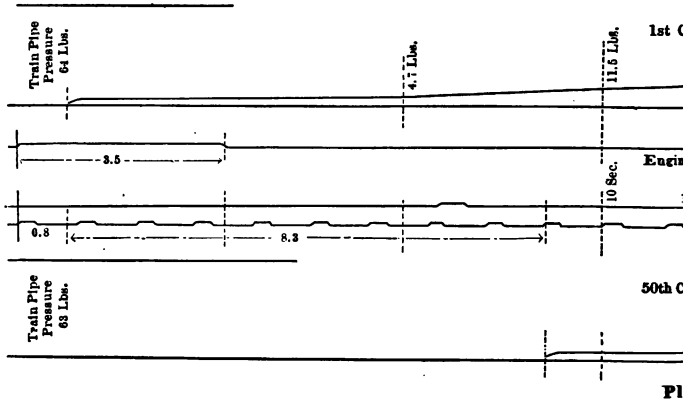
WESTINGHOUSE AIR BRAKE TRAIN.

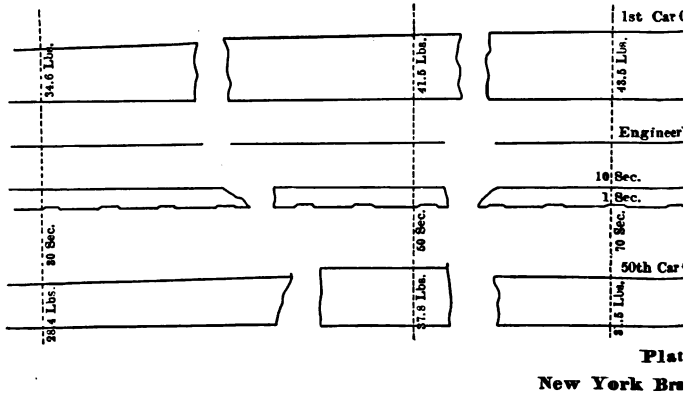
In .7 of a second after the movement of the engineer's valve the pressure commenced in the first car.

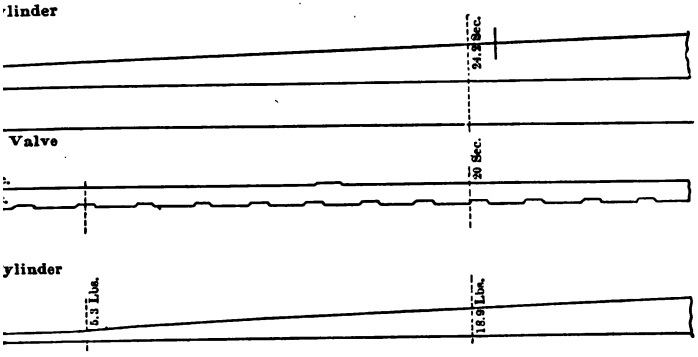
Pressure in Pounds, Time Intervals in Seconds.

Seconds	6.8	10	20	30	40	50	60	Release Occupied.
First Car	6.3	11.6	24.2	36.3	38.8	37.5	33.6	7 Seconds.
Fiftieth Car	3.2	4.2	11.6	22.	28.3	31.5	28.4	6½ do.

TEST No. 6.—The engineer, in trying to open the brake-valve to the emergency notch 1 second, as directed, was more deliberate than he would be in making the emergency application when running; 0.05 to 0.06 of a second is the possible time from the locomotive to the first car. The automatic trip indicated 0.04 to 0.05 of a second.

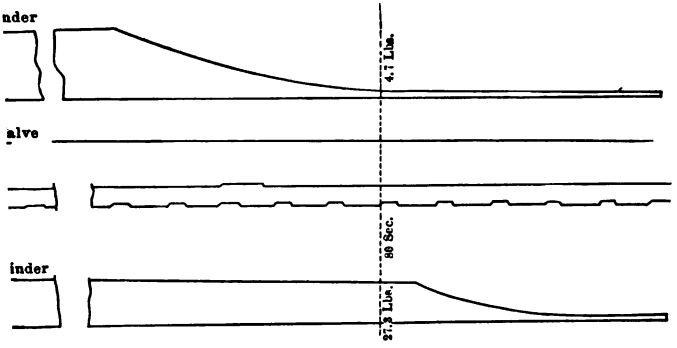

Train Pipe Pressure 64 Lbs.
4.7 Lbs.
11.5 Lbs.
1st C
3.5
Engi
10 Sec.
0.8
8.3
Train Pipe Pressure 63 Lbs.
50th C
Pl
New York B


1st Car
34.6 Lbs.
41.5 Lbs.
48.5 Lbs.
Engineer
10 Sec.
1 Sec.
80 Sec.
60 Sec.
70 Sec.
38.4 Lbs.
37.8 Lbs.
50th Car
Plat
New York Bra



e X

ke. Test No. 5.



XI

. Test No. 5.

Air Brake Tests

THE KARNER TESTS

The diagrams and tabulations of test No. 6 show at a glance the distinctive character between the action of the two triples in the emergency application, each being constructed upon a different theory regarding the best application of air for such uses. The New York applies rapidly up to 40 lbs., then more slowly, equalizing at a higher pressure of 1 or 2 lbs., than is usual. Three seconds is about the time consumed per car in attaining the maximum pressure.

The Westinghouse applies rapidly, reaching in about 1 second the maximum pressure per car, which for the same trainpipe pressure is 1 to 2 lbs. lower than the New York. The slower application of the New York does not permit of reaching a maximum pressure of 55 lbs. in 3½ seconds on the fiftieth car, as is the case with the Westinghouse.

TEST No. 6.—TABLE XXIX.—NEW YORK AIR BRAKE TRAIN (Three Trials)
See Diagram in Plate No. XII.

No. of Trial.	Trainpipe Pressure.		Time of First Movement of Engineer's Valve to First Car.	First Car Time and Maximum Pressure.		Fiftieth Car Time of Application and Maximum Pressure.		
	Car.		Seconds.	Seconds.	Pounds.	Seconds.		Pounds.
	First.	Fiftieth.						
First . . .	69.3	69.3	0.25	3.6	58.80	3.38	6.20	55.65
Second . .	. . .	. . .	0.24	3.2	59.85	3.30	6.20	57.75
Third . . .	. . .	. . .	0.28	3.2	61.95	3.30	6.20	58.25

WESTINGHOUSE AIR BRAKE TRAIN (Three Trials).
See Diagram, Plate No. XIII.

No. of Trial.	Trainpipe Pressure.		Time of First Movement of Engineer's Valve to First Car.	First Car Time and Maximum Pressure.		Fiftieth Car Time of Application and Maximum Pressure.		
	Car.		Seconds.	Seconds.	Pounds.	Seconds.		Pounds.
	First.	Fiftieth.						
First . . .	. . .	. . .	0.30	1.30	57.75	2.9	3.8	55.65
Second . .	68.3	68.3	0.20	1.20	58.75	2.8	3.7	55.65
Third . . .	. . .	. . .	0.20	1.20	57.75	2.75	3.65	55.65

In the three trials of No. 6 test with the Westinghouse train one car leaked off.

THE KARNER TESTS

Air Brake Tests

TEST No. 7.

Time of development of pressure in cylinders, the fifth, sixth, and seventh cars cut out. Emergency application and release. Repeated three times.

NEW YORK TRAIN.

TEST No. 7.—First trial. First car applied in .2 seconds. Fiftieth car applied in 3.7 seconds. First car reached a pressure of 60.9 lbs. in 3 seconds. Fiftieth car reached a pressure of 57.8 lbs. in 6.5 seconds.

First car released at 58.8 lbs. and the fiftieth car released in 7¼ seconds after the first.

TEST No. 7.—Second trial, failed. Trainpipe, 69.30 lbs. in the first car. Trainpipe, 70.35 lbs. in the fiftieth car.

TEST No. 7.—Third trial, failed.

TEST No. 7.—Fourth trial, failed. Trainpipe pressure 69.30 lbs. first car. Trainpipe pressure, 66.15 lbs. fiftieth car.

TEST No. 7.—Fifth trial: Engineer's valve open two seconds. Trainpipe pressure 69.30 first car. Trainpipe pressure 66.15 fiftieth car.

The first car developed a pressure of 60.90 lbs., in 2.7 seconds and the fiftieth car applied in 4.2 seconds from the movement of the engineer's valve, and reached a pressure of 57.75 lbs. in 7 seconds.

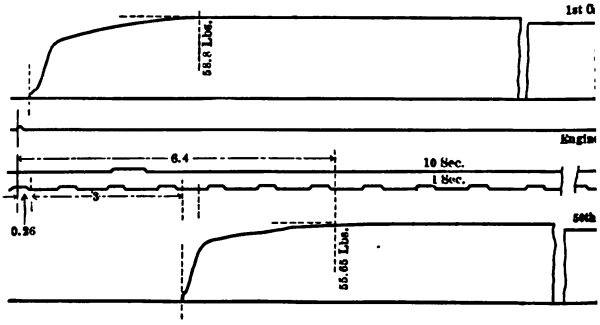
WESTINGHOUSE TRAIN.

TEST No. 7.—First trial: Trainpipe 68.30 lbs., first car. Trainpipe 67.20 lbs., fiftieth car.

In 0.2 seconds after movement of engineer's valve, first car applied and in 1.1 seconds reached a maximum pressure of 57.80 lbs. The fiftieth car commenced to apply in 2.6 seconds and reached a maximum pressure of 55.55 lbs., in 3.6 seconds. Brakes all on, and all released.

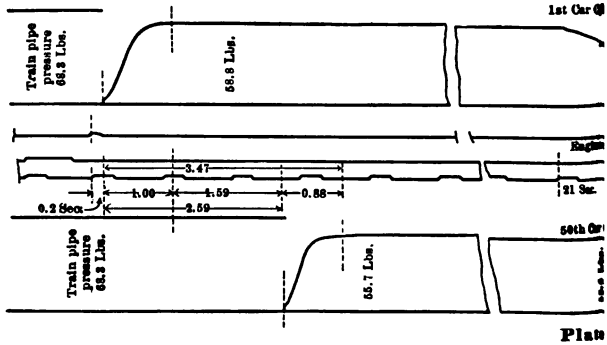
TEST No. 7.—Second trial: Trainpipe 68.25 lbs., first car. Trainpipe 67.20 lbs., fiftieth car.

In 0.2 seconds from movement of engineer's valve first car commenced to apply and in 1.1 seconds reached a maximum pressure of



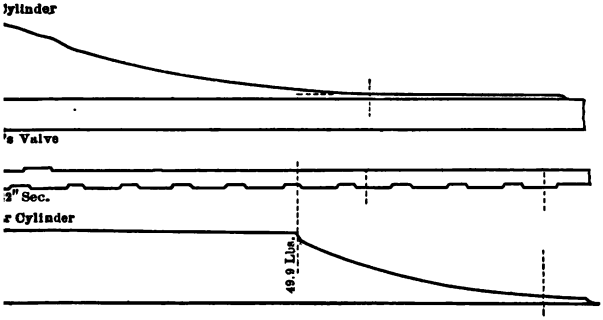
Plat

New York Br



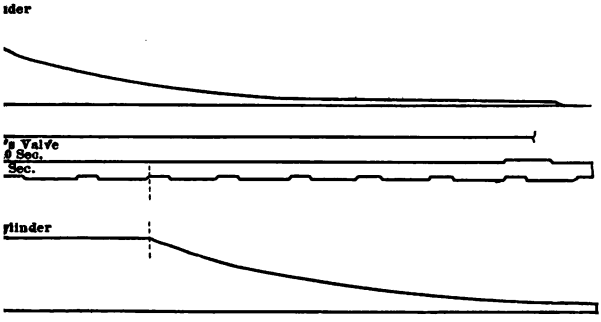
Plate

Westinghouse Brake. F



XII

ke. Test No. 6.



XIII

st No. 6. (Second Trial.)

THE KARNER TESTS

57.75 lbs.; fiftieth car commenced to apply in 2.7 seconds and reached a maximum pressure of 55.65 lbs., in 3.6 seconds.

TEST No. 7.—Third trial: A duplicate of trial No. 2 except the fiftieth car was 3.65 seconds in reaching 55.65 lbs.

TEST No. 8.—SPECIAL AND OPTIONAL.

Same as No. 7, except that the fifth to the tenth car inclusive was cut out. The New York Brake Co. did not choose to make this trial.

In practical operations it is often quite as important to know what can not be done as it is to know what can be done.

The Westinghouse Co. made the trial. The handle of the engineer's valve was held in the emergency notch 1 second, as usual. In four trials the emergency action beyond the cut out cars did not take place, then the forward rush of air with its stored energy would release the brakes.

TEST No. 9.—GRADUATION TESTS.

A reduction of 8 lbs. in trainpipe pressure was made, then at 1 minute intervals, further reductions of 4 to 6 lbs. were made until reservoirs and cylinders were equalized. Repeated twice.

NEW YORK TRAIN.

TEST No. 9.—First trial: Trainpipe pressure reduced to 8 lbs. Pressure in trainpipe, first car, 69.30 lbs. Pressure in trainpipe, fiftieth car, 67.20 lbs.

First car applied to in 0.9 of a second after movement of engineer's valve, and the fiftieth car in 9 seconds. In 20 seconds the pressure in the first car, 23.1 lbs.; fiftieth car, 15.75 lbs.

In 1 minute pressure, in first car, 18.90 lbs.; fiftieth car, 10.50 lbs.

Second application:

One minute, trainpipe pressure, 57.75 lbs.

In 10 seconds, pressure in first car, 40.95 lbs.; fiftieth car, 21.00 lbs. In 1 minute, pressure in first car, 34.65 lbs.; fiftieth car, 13.65 lbs.

It was noticed that the effect of the second application was felt in the fiftieth car in 4 to 5 seconds, about one-half of the time of the first application. This seemed to be the rule with both brakes.

Several applications were made at minute intervals, the seventh not affecting the cylinders in either car.

Eleven cars were reported as not applying beyond the leakage groove.

The second trial of Test No. 9 was similar to the first, until the third application, which applied the brakes in full, as the fourth and fifth applications did not increase the pressure in either the first or fiftieth cars.

Six cars were reported as not applying beyond the leakage groove.

WESTINGHOUSE TRAIN.

Trainpipe pressure, first car, 68.25 lbs.; fiftieth car, 67.20 lbs.

In 0.5 of a second brakes applied in first car, and in 6.7 in the fiftieth car. In 10 seconds, first car, 8.40 lbs., and in the fiftieth car, 4.20 lbs.

At the minute, first car, 8.40 lbs.; fiftieth car, 7.35 lbs.

Ten seconds after the second application, first car, 26.25 lbs.; fiftieth car, 15.75 lbs.

Five applications were made in this test.

TEST NO. 9. — Second trial: In 0.6 of a second brakes applied in first car, and in 6.9 seconds on the fiftieth car. This trial was similar to the others, except that seven applications were made. All brakes applied in both trials.

TEST NO. 10. — SERVICE APPLICATION.

Fifteen pounds to be admitted into cylinders, pressure noted then at the 5th, 10th, and 15th minutes.

NEW YORK TRAIN.

TEST NO. 10. — The first car applied in 0.7 of a second, and the fiftieth car in 9 seconds.

At 50 seconds, first car, 52.50 lbs.; fiftieth car, 38.85 lbs.

THE KARNER TESTS

At 5 minutes, first car, 47.25 lbs.; fiftieth car, 5.25 lbs.

At 10 minutes, first car, 40.95 lbs.; fiftieth car, 2.10 lbs.

At 15 minutes, first car, 37.80 lbs.; fiftieth car, 2.10 lbs.

After the first 5 minutes 6 cars had released.

After 10 minutes 2 more were also off; all the others remained on 15 minutes.

WESTINGHOUSE TRAIN.

Trainpipe pressure, first car, 68.25 lbs.; fiftieth car, 67.20 lbs.

Brakes applied in first car in 0.9 seconds, and in the fiftieth car in 6½ seconds.

In 40 seconds, pressure was in first car, 31.50 lbs.; fiftieth car, 26.25 lbs.

In 5 minutes, pressure in first car, 5.25 lbs.; fiftieth car, 4.20 lbs.

At 10 and 15 minutes the readings were down to zero in both cars. The readings were affected by the indicators and their connections. All of the cars applied.

One car released at the end of 5 minutes, and in 11 minutes another car, and a third car in 12 minutes; all the others remained on 15 minutes.

TEST NO. 11.

Same as No. 10, except *all the air* was exhausted from trainpipe by emergency application.

NEW YORK TRAIN.

All brakes applied, and none leaked off fully at the end of 15 minutes.

WESTINGHOUSE TRAIN.

Mr. Wm. Buchanan, Superintendent Motive Power and Rolling Stock, requested that the time be extended in this test to 30 minutes, which was done, the New York train being subsequently tested the same length of time on another track. All Westinghouse brakes applied and remained on the 30 minutes, except one car which leaked off.

TEST NO. 12.—RELEASE TEST.

Boiler pressure, 160 lbs.: With 70 lbs. in the trainpipe, all the air was discharged by an emergency application. A pressure of 90

lbs. was then maintained against a diaphragm $\frac{1}{8}$ in. thick, perforated with $\frac{3}{32}$-in. hole, and a record taken of all brakes, which released in 30 minutes.

NEW YORK TRAIN.

Pressure 22 lbs. in 5 minutes. One car released in 2 minutes; three in 3 minutes; four in 4 minutes; three in 5 minutes—or eleven in 5 minutes or under.

At 10 minutes the pressure was 40 lbs. Six cars released in 6 minutes; ten in 8 minutes; seven in 10 minutes.

At 15 minutes the pressure in trainpipe was 47 lbs. Eleven cars released in 14 minutes. At the end of 30 minutes one car did not release.

WESTINGHOUSE TRAIN.

Trainpipe pressure at the end of 5 minutes, 10.50 lbs.; 10 minutes, 38.85 lbs.; 15 minutes, 53.55 lbs.; 20 minutes, 59.85 lbs.; 30 minutes, 70.36 lbs.

One car released in 5 minutes; two in 6 minutes; six in 10 minutes; seven in 11 minutes; nine in 12 minutes; ten in 15 minutes; twelve in 18 minutes; three did not release at the end of 30 minutes.

TEST NO. 13.

Test to determine the sensitiveness of the emergency valve.

The first and fiftieth car was cut from the train and connected together by hose; 70 lbs. pressure was then maintained and discharged into the trainpipe through a diaphragm perforated with $\frac{5}{32}$-in. hole. Each car to be tested singly, if desired.

NEW YORK TRAIN.

Trainpipe, 71.40 lbs. First trial, emergency action occurred in both cars. Second trial, emergency action did not occur. Third trial, emergency action did not occur. Fourth trial, first car only, emergency action occurred. Fifth trial, emergency action occurred. Sixth, seventh and eighth trials, with the fiftieth car, emergency action did not occur.

Air Brake Tests

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WESTINGHOUSE TRAIN.

Trainpipe 72.45 lbs. First and fiftieth cars, emergency action did not occur. Second trial, emergency action did not occur. Third trial, emergency action did not occur. Fourth trial, first car only, emergency action occurred. Fifth and sixth trials, fiftieth car only, emergency action did not occur.

TEST NO. 14.

Test to determine time of charging one auxiliary reservoir. Cars arranged as in test No. 13, only brakes cut out and reservoir pressure bled off. Ninety lbs. pressure secured in main air reservoir and train-pipe; pump shut off and time of charging reservoir to 70 lbs. noted.

NEW YORK TRAIN.

First car charged in 72 seconds. Fiftieth car charged in 60 seconds.

WESTINGHOUSE TRAIN.

First car charged in 70 seconds. Fiftieth car charged in 80 seconds.

SECOND TRIAL.— First car charged in 69 seconds. Fiftieth car charged in 87 seconds.

RUNNING TRIALS.

The Westinghouse train was assigned to track No. 4 and the New York train to track No. 3. The governors for the air pressure were set in the morning of the 9th. The brakes on each tender were also adjusted after the locomotives were attached to the trains.

Determination of Speed of the Running Trains.

It was impracticable for the Dynagraph car to be on either train, so electrical trips were erected on each track 88 feet apart, or $\frac{1}{60}$ of a mile.

Both tracks were supplied with these trips; one being located 88 feet above the signal banner; another at the banner to give the initial speed, and the others at proper intervals extending several hundred feet below the signal banner. These were in circuit with the electro-magnetic pens of the recording mechanism of the Dynagraph car which stood upon a side track near where the stops would occur; then by

running the paper as the train passes, the interval of time in running over the spaces would be recorded.

The trips had a base-board 5 in. wide by 24 in. long, in the center of which was secured a block carrying a tripping pawl, which held in position a gravity lever, its fulcrum being near its lower end. Back of this gravity lever was a spring and contact point for a circuit closer; the circuit was open when the gravity lever was up, but when released and falling, closed the circuit about $\frac{1}{20}$ of a second; then the spring opened the circuit during the last part of the fall to leave the circuit free to be closed and opened by the next trip, and so on.

The forward truck wheel operated the tripping pawl. These trips were very carefully adjusted as to the length of contact and the exact angle at which they would close the circuit during their fall.

The records obtained from these trips after the air was applied only refer to the speed of the locomotives and not to that of the entire train; the front, middle, and rear portions having different velocities for a few seconds during retardation.

A banner directly over the tripping blocks in tracks Nos. 3 and 4 was the signal for the engineers to shut off steam when the cabs were under it; the levers being tripped at the same point, applied the air with a precision and quickness impossible by the engineer's valve.

To give the locomotives distance to work up the speed desired, the trains were backed two miles for thirty miles per hour and under, and for higher speeds three miles, and then ran side by side on parallel tracks to the signal banner at as near the same speed as possible; with the exception of No. 4 run, both engines reached the banner nearly at the same instant. The trains were run with great skill; much better than it was thought possible to handle such long trains, and the engineers are entitled to great credit for their work.

The tabulations of the observed data of the running trials are so explicit as to require but little further explanation, and this will generally be given with the energy diagrams. The only calculations in the tabulations are those for the speeds, from the times given by the trips, which have been carefully revised, and, with the exception of trip

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No. 4, the initial speeds are closer approximations than are usually obtained.

The time of stop only refers to the Westinghouse train, as the other could not be observed from the car; when the train parted, the time is shorter than the time of the movement of the locomotive.

The gauge readings of the observers have been corrected to the readings of the standard gauge. In the running trials, the readings of the gauges on the trainpipe could be correctly obtained, while those for the reservoirs and cylinders were more difficult to read correctly. In the five comparative runs, except in No. 4, the train running the farthest had the highest trainpipe pressure, but the slower rate of development in the cylinders, though finally attaining a higher maximum pressure.

The time of application per car and train were given in the standing tests in the tables of No. 6 tests, and the curves of development of pressure per cylinder by the indicator diagrams of the same tests.

Energy Diagrams.

From the observed speeds of the locomotive, for each train and trial, curves of their retardation were plotted by full lines for the observed spaces, then to the point of the stop by a broken line, the latter being only a general approximation.

There was also added an approximate curve of broken lines or dashes to represent for the center of gravity of the train its total energy and rate of destruction. There should also be added a third curve to represent the energy of the rear unbraked cars; for as they continue their speed they not only compress the draw-bar springs but push the front of the train and locomotive beyond the point where they would have stopped had their rate of retardation remained unchanged. This is shown in all the energy diagrams.

In the slower trials it was about 3 seconds before the locomotive was affected, while in the higher speeds it was 4 or more seconds.

TABLE XXX.— RUNNING TRIALS No. 1. TEMPERATURE 72° FAHR.
Time 11.30 A. M.

			Westinghouse Train.		New York Train.	
			Miles per hour.	Time, seconds.	Miles per hour.	Time, Seconds.
Initial speed			26.78	2.24	26.78	2.24
First 88 feet			25.32	2.37	25.86	2.32
Second 88 "			21.12	2.84	22.69	2.64
Third 88 "			. .	. .	. .	. .
Fourth 88 "			. .	. .	. .	. .
Length of stop			270 feet		310 feet	
Time of stop			10.6 seconds		. . . . .	
Slideometer	First car		.25 inch	.25 inch	1.75 inches	
	Fiftieth car		4 inches		26.50 inches	
			Charged.	Applied.	Charged.	Applied.
Air pressure	First car	Trainpipe	68.	00.	71.	26.
		Reservoir	68.	56.	71.	59.
		Cylinder	00.	56.	00.	58.50
	Fiftieth car	Trainpipe	68.	23.	71.	40.
		Reservoir	68.	55.	71.	59.
		Cylinder	00.	55.	00.	59.

TABLE XXXI.— RUNNING TRIALS No. 2. TEMPERATURE 80° FAHR.
Time 12.00 M.

			Westinghouse Train.		New York Train.	
			Miles per hour.	Time, seconds.	Miles per hour.	Time, seconds.
Initial speed			32.00	1.875	32.00	1.875
First 88 feet			31.17	1.925	31.58	1.900
Second 88 "			29.54	2.037	29.70	2.020
Third 88 "			. .	2.17	27.06	2.217
Fourth 88 "			19.44	4.00	. .	. .
176 feet						
Length of Stop			373 feet		450 feet	
Time of stop			11.50 seconds		. . . .	
Slideometer	First car		.25 inch	.75 inch	.5 inch	.75 inch
	Fiftieth car		.50 inches		31.00 inches	
			Charged.	Applied.	Charged.	Applied.
Air pressure	First car	Trainpipe	68.5	27.	71.	20.
		Reservoir	68.	57.	71.	55.
		Cylinder	00.	57.	00.	54.
	Fiftieth car	Trainpipe	68.	47.	70.5	00.
		Reservoir	68.	50.	70.5	58.
		Cylinder	00.	49.	00.	58.

NOTE.— Broken brake-beam on tender of engine on the New York train; track No. 3; last car uncoupled.

TABLE XXXII.— RUNNING TRIALS No. 3. TEMPERATURE 80° FAHR.
Time 2.10 P. M.

			Westinghouse Train.		New York Train.	
			Miles per hour.	Time, seconds.	Miles per hour.	Time, seconds.
Initial speed			34.48	1.74	34.48	1.74
First 88 feet			33.74	1.778	33.99	1.762
Second 88 "			31.43	1.906	32.26	1.860
Third 88 "			27.77	2.160	28.82	2.079
Fourth 88 "			22.89	2.622	. .	. .
Length of stop			472′; train parted 34.8′ between fifth and sixth cars; broken knuckles.		496′; train parted 38.3′ betw'n twelfth and thirteenth cars; broken knuckles.	
Time of stop			. . .		. . .	
Slideometer	First car		.5 inch		.5 inch	.1 inch
	Fiftieth car		.5 do		28.25 inches	
			Charged.	Applied.	Charged.	Applied.
Air pressure	First car	Trainpipe	64.50	00.	69.	20.
		Reservoir	63.50	54.	69.	53.
		Cylinder	00.	54.	00.	53.
	Fiftieth car	Trainpipe	65.	47.	70.	41.
		Reservoir	64.5	47.	69.	58.
		Cylinder	00.	45.	00.	58.

TABLE XXXIII.— RUNNING TRIALS No. 4. TEMPERATURE 78° FAHR.
Time 3.20 P. M.

			Westinghouse Train.		New York Train.	
			Miles per hour.	Time, seconds.	Miles per hour.	Time, seconds.
Initial speed			30.30	1.980	31.88	1.882
First 88 feet			30.00	2.00	31.39	1.911
Second 88 "			25.72	2.333	28.29	2.121
Third 88 "			20.41	2.939	25.07	2.393
Fourth 88 "			. .	. .	. .	. .
Length of stop			325 feet. Parted about one car length.		417 feet. Parted about one car length.	
Time of stop			11 seconds		. . .	
Slideometer	First car		00.		$\frac{7}{8}$ inch	
	Fiftieth car		6. inches		26.5 inches	
			Charged.	Applied.	Charged.	Applied.
Air pressure	First car	Trainpipe	72.	00.	65.	00.
		Reservoir	71.	60.	65.	53.
		Cylinder	00.	59.	00.	47.
	Fiftieth car	Trainpipe	72.	28.	63.	23.
		Reservoir	71.	56.	63.	53.
		Cylinder	00.	56.	00.	53.

NOTE.— This was ordered for a speed of 40 miles per hour, but the driver brakes were stuck on the New York engine and the other engine was slowed down to her speed.

TABLE XXXIV.— RUNNING TRIALS No. 5. TEMPERATURE 77° FAHR.

			Westinghouse Train.		New York Train.	
			Miles per hour.	Time, seconds.	Miles per hour.	Time, seconds.
Initial speed			28.39	2.113	28.39	2.113
First 88 feet			28.39	2.113	28.39	2.113
Second 88 "			28.39	2.113	28.39	2.113
Third 88 "			28.18	2.131	27.94	2.147
Fourth 88 "			26.47	2.267	. .	. .
Length of stop			844 feet		957.5 feet	
Time of stop			. . .		. . .	
Slideometer	First car		00.		$\frac{3}{8}$ inch	
	Fiftieth car		3. inches		1.25 inches	
			Charged.	Applied.	Charged.	Applied.
Air pressure	First car	Trainpipe	68.	46.	70.5	50.
		Reservoir	68.	46.	70.5	50.
		Cylinder	00.	45.	00.	45.
	Fiftieth car	Trainpipe	68.	36.	67.	50.
		Reservoir	68.	44.	67.	50.
		Cylinder	00.	33.	00.	50.

NOTE.— Service stop by air passing through a diaphragm perforated with a $\frac{8}{32}$-in. hole.

TABLE XXXV.— RUNNING TRIALS NOS. 6 AND 7. TEMPERATURE 70° FAHR.
Time of No. 6, 5.38 P. M.; No. 7, 5.45 P. M.

			Test No. 6. Mixed Forty-Five Cars.		Test No. 7. Mixed Fifty-Five Cars.	
			Miles per hour.	Time, seconds.	Miles per hour.	Time, seconds.
Initial speed			27.75	2.162	30.00	2.00
First 88 feet			27.44	2.186	29.27	2.05
Second 88 "			25.62	2.342	25.63	2.341
Third 88 "			19.84	3.024	20.83	2.881
Fourth 88 "			. .	. .	. .	. .
Length of stop			325 feet. Parted it two places, about forty-five feet.		344 feet. Parted in three places.	
Time of stop			10.3 seconds		. . .	
Slideometer	First car		00.		$\frac{1}{4}$ and $\frac{3}{4}$ inch	
	Fiftieth car		10.25 inches		23.5 inches	
			Charged.	Applied.	Charged.	Applied.
Air pressure	First car	Trainpipe	65.	00.	72.	22.5
		Reservoir	64.	53.	72.	58.
		Cylinder	00.	53.	00.	54.
	Fiftieth car	Trainpipe	63.	30.	70.	25.
		Reservoir	64.	52.	70.	55.
		Cylinder	00.	50.	00.	55.

NOTE.— Train of trial No. 6, composed of twenty-five cars Westinghouse brakes and twenty cars New York brakes, mixed. Train of trial No. 7, composed of thirty cars New York brakes and twenty-five cars Westinghouse brakes, mixed.

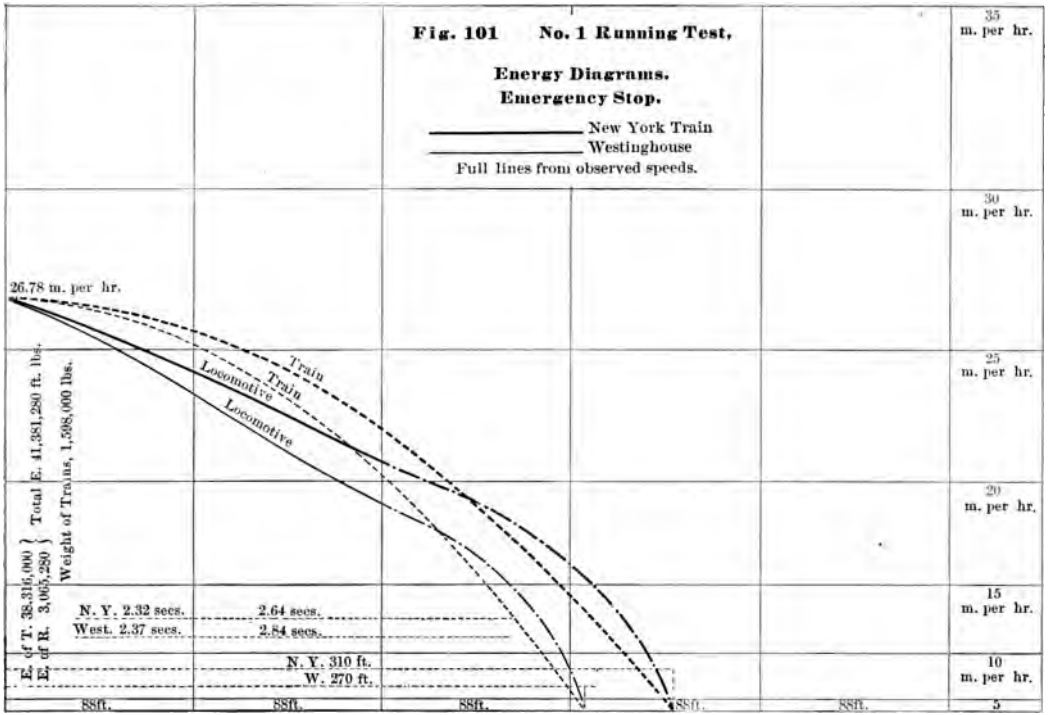


Fig. 101 No. 1 Running Test.
Energy Diagrams.
Emergency Stop.
New York Train
Westinghouse
Full lines from observed speeds.
35 m. per hr.
30 m. per hr.
25 m. per hr.
20 m. per hr.
15 m. per hr.
10 m. per hr.
5
26.78 m. per hr.
Train
Locomotive
Train
Locomotive
E. of T. 38,316,000 } Total E. 41,381,280 ft. lbs.
E. of R. 3,065,280 } Weight of Trains, 1,598,000 lbs.
N. Y. 2.32 secs.
West. 2.37 secs.
2.64 secs.
2.84 secs.
N. Y. 310 ft.
W. 270 ft.
88ft.
88ft.
88ft.
88ft.
88ft.

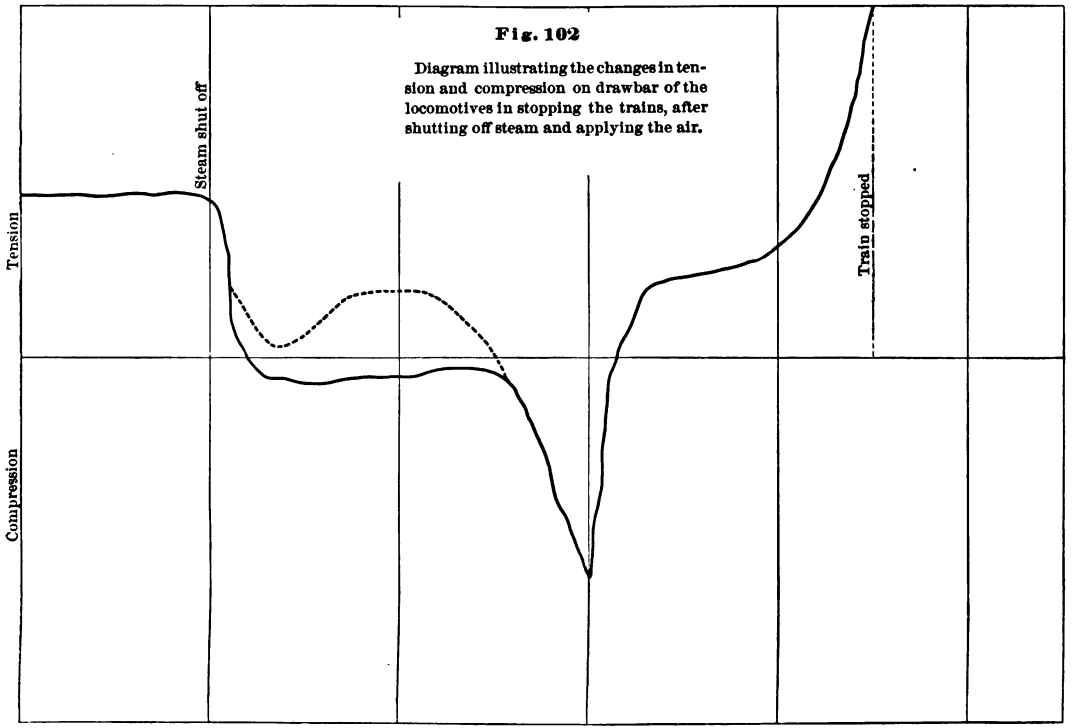


Fig. 102

Diagram illustrating the changes in tension and compression on drawbar of the locomotives in stopping the trains, after shutting off steam and applying the air.

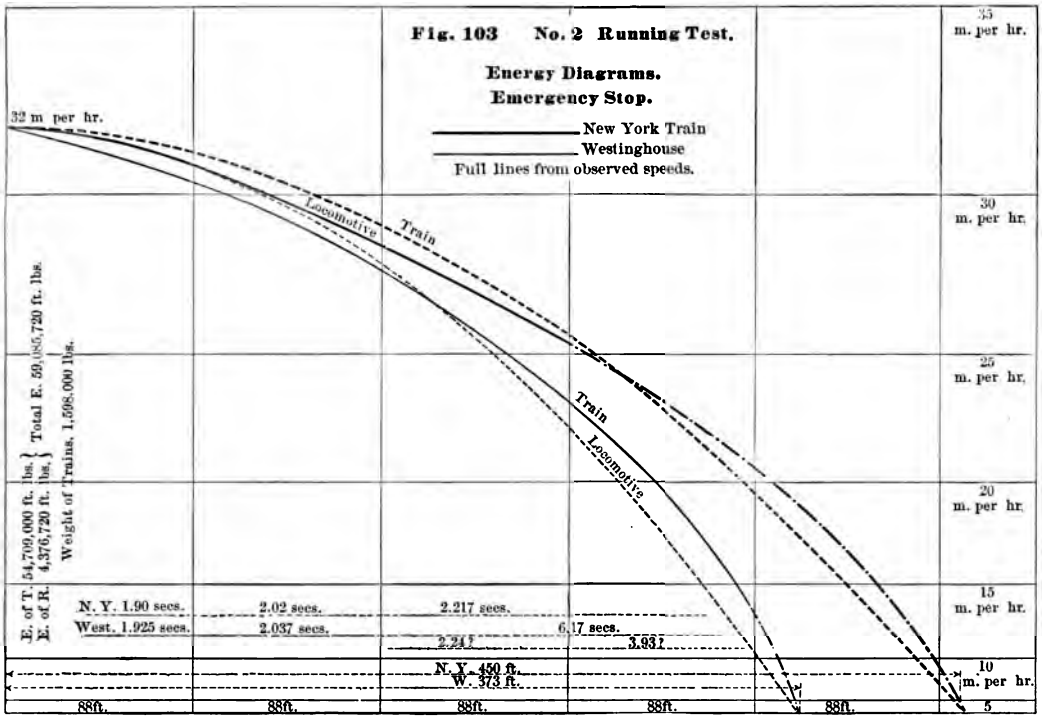


Fig. 103 No. 2 Running Test.
Energy Diagrams.
Emergency Stop.
New York Train
Westinghouse
Full lines from observed speeds.
32 m per hr.
Locomotive
Train
Train
Locomotive
35 m. per hr.
30 m. per hr.
25 m. per hr.
20 m. per hr.
15 m. per hr.
10 m. per hr.
5
E. of T. 54,709,000 ft. lbs.
E. of R. 4,376,720 ft. lbs.
Total E. 59,085,720 ft. lbs.
Weight of Trains, 1,598,000 lbs.
N. Y. 1.90 secs.
West. 1.925 secs.
2.02 secs.
2.037 secs.
2.217 secs.
2.245
6.17 secs.
3.937
N. Y. 450 ft.
W. 373 ft.
88ft.
88ft.
88ft.
88ft.
88ft.

THE KARNER TESTS

In the energy diagrams showing the curves of both trains, in trial No. 1, diagram in Fig. 101, the speed of the locomotives was retarded in the first 88 ft., and had the same rate continued would have stopped many feet short of the actual stop. In the second 88 ft. the locomotives were pushed forward by the energy of the rear cars; while in the next 88 ft. the locomotives were again being retarded by the train.

The general changes in tension and compression on the draw-bar of the locomotives at Karner are illustrated by a special diagram, Fig. 102.

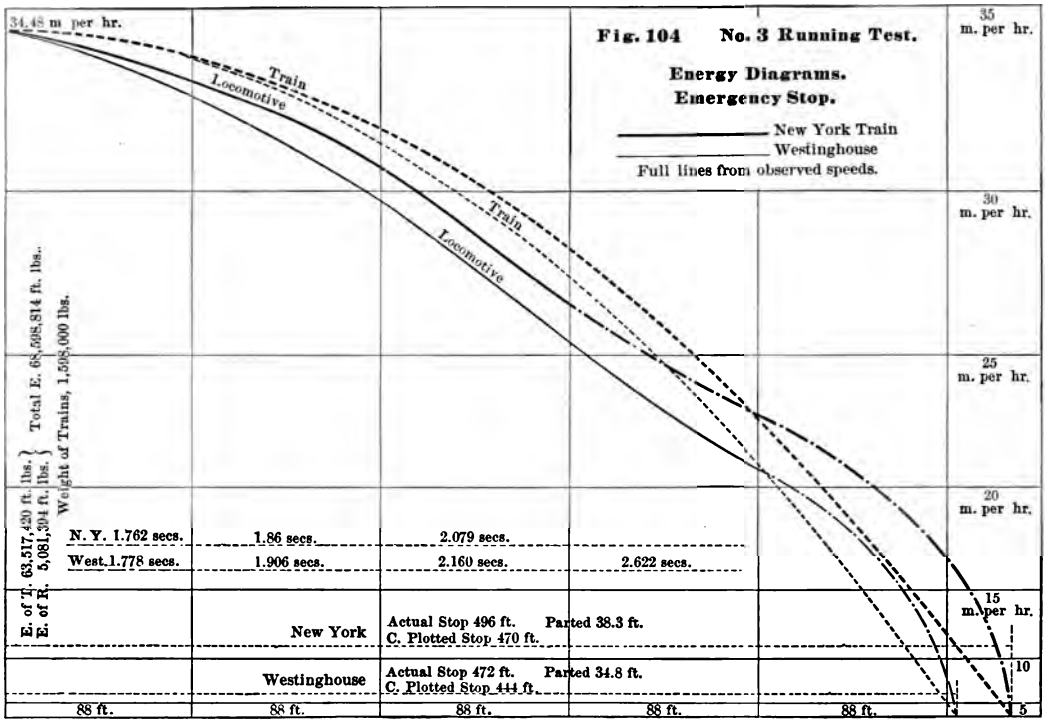
Trial No. 2, diagram in Fig. 103, at 32 miles per hour, with over 59,000,000 foot lbs. of energy to destroy, is one of the most important diagrams of the series. The vast amount of energy was not only quickly destroyed, but without the slightest injury to the trains.

The speed of the locomotive for the Westinghouse train was obtained to within a few feet of the stop and shows closely its curve or retardation; first, the rapid retardation; second, the checking of its rate; third, rapid retardation.

The obtained speed of the locomotive of the New York train is one space short of the Westinghouse train, yet its curve of retardation is closely shown.

Trial No. 3, diagram in Fig. 104, a speed of 34.48 miles per hour, shows a total energy of 68,598,814 foot lbs. for each train, capable of doing work equivalent to raising the entire train over 40 ft. above the track. Anyone will understand that if a train was allowed to fall 40 ft., the locomotive and every car would be a wreck. The same amount of energy was destroyed by the brakes in a harmless way in about one-fourth of the train's length, a broken knuckle on each train being the only thing to indicate that any great amount of work had been done. The speed for the distance run was a greater tax upon the locomotives than in the preceding trials, the steam and air pressure falling slightly. Both trains parted just before the stop, an allowance being made in plotting each curve as shown on the diagrams.

Trial No. 4, diagram in Fig. 105, was ordered for a speed of 40


34.48 m. per hr.
Train
Locomotive
Fig. 104 No. 3 Running Test.
Energy Diagrams.
Emergency Stop.
New York Train
Westinghouse
Full lines from observed speeds.
35 m. per hr.
30 m. per hr.
25 m. per hr.
20 m. per hr.
15 m. per hr.
10
5
Total E. 68,508,814 ft. lbs.
Weight of Trains, 1,508,000 lbs.
E. of T. 63,517,420 ft. lbs.
E. of R. 5,081,394 ft. lbs.
N. Y. 1.762 secs.
1.86 secs.
2.079 secs.
West. 1.778 secs.
1.906 secs.
2.160 secs.
2.622 secs.
New York
Actual Stop 496 ft. Parted 38.3 ft.
C. Plotted Stop 470 ft.
Westinghouse
Actual Stop 472 ft. Parted 34.8 ft.
C. Plotted Stop 444 ft.
88 ft.
88 ft.
88 ft.
88 ft.
88 ft.

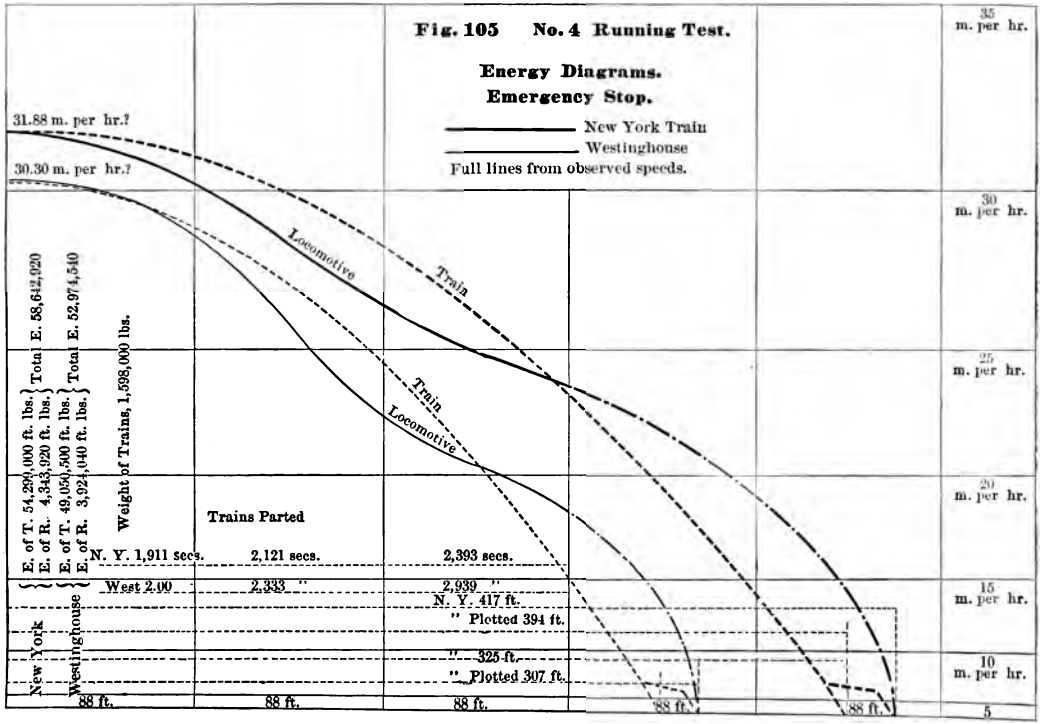


Fig. 105 No. 4 Running Test.
Energy Diagrams.
Emergency Stop.
New York Train
Westinghouse
Full lines from observed speeds.
31.88 m. per hr.?
30.30 m. per hr.?
Locomotive
Train
Train
Locomotive
35 m. per hr.
30 m. per hr.
25 m. per hr.
20 m. per hr.
15 m. per hr.
10 m. per hr.
5
Total E. 58,642,920
Total E. 52,974,540
E. of T. 54,299,000 ft. lbs.
E. of R. 4,343,920 ft. lbs.
E. of T. 49,050,500 ft. lbs.
E. of R. 3,924,040 ft. lbs.
Weight of Trains, 1,598,000 lbs.
Trains Parted
N. Y. 1,911 secs.
2,121 secs.
2,393 secs.
West 2.00
2,333 "
2,939 "
N. Y. 417 ft.
" Plotted 394 ft.
" 325 ft.
" Plotted 307 ft.
New York
Westinghouse
88 ft.
88 ft.
88 ft.
88 ft.
88 ft.

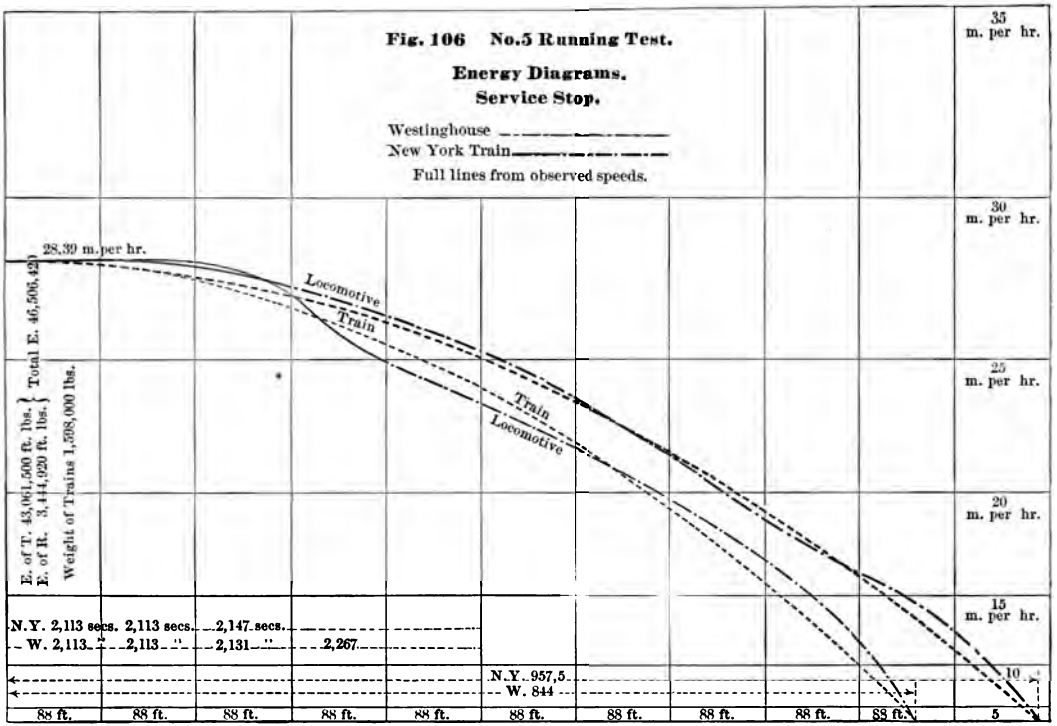


Fig. 106 No.5 Running Test.
Energy Diagrams.
Service Stop.
Westinghouse
New York Train
Full lines from observed speeds.
35 m. per hr.
30 m. per hr.
25 m. per hr.
20 m. per hr.
15 m. per hr.
10
28.39 m. per hr.
Total E. 46,506,420
E. of T. 43,061,500 ft. lbs.
E. of R. 3,444,920 ft. lbs.
Weight of Trains 1,598,000 lbs.
Locomotive
Train
Train
Locomotive
N.Y. 2,113 secs. 2,113 secs. 2,147 secs.
W. 2,113 " 2,113 " 2,131 " 2,267
N.Y. 957,5
W. 844
88 ft. 88 ft. 88 ft. 88 ft. 88 ft. 88 ft. 88 ft. 88 ft. 88 ft. 88 ft. 5

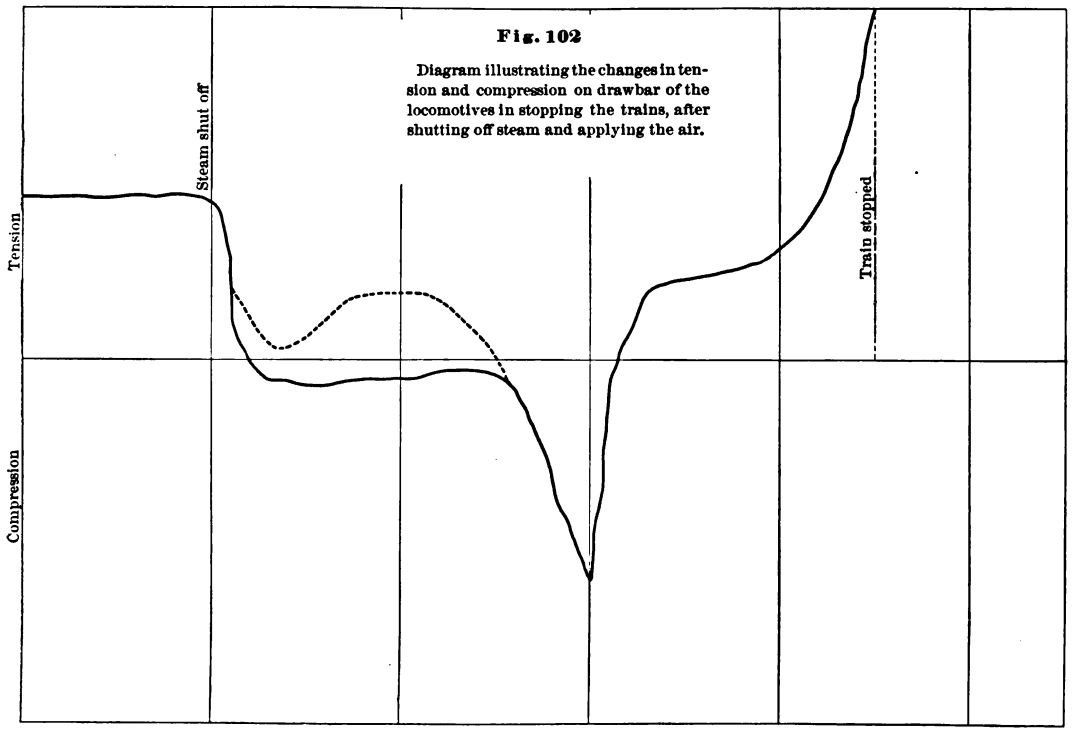


Fig. 102

Diagram illustrating the changes in tension and compression on drawbar of the locomotives in stopping the trains, after shutting off steam and applying the air.

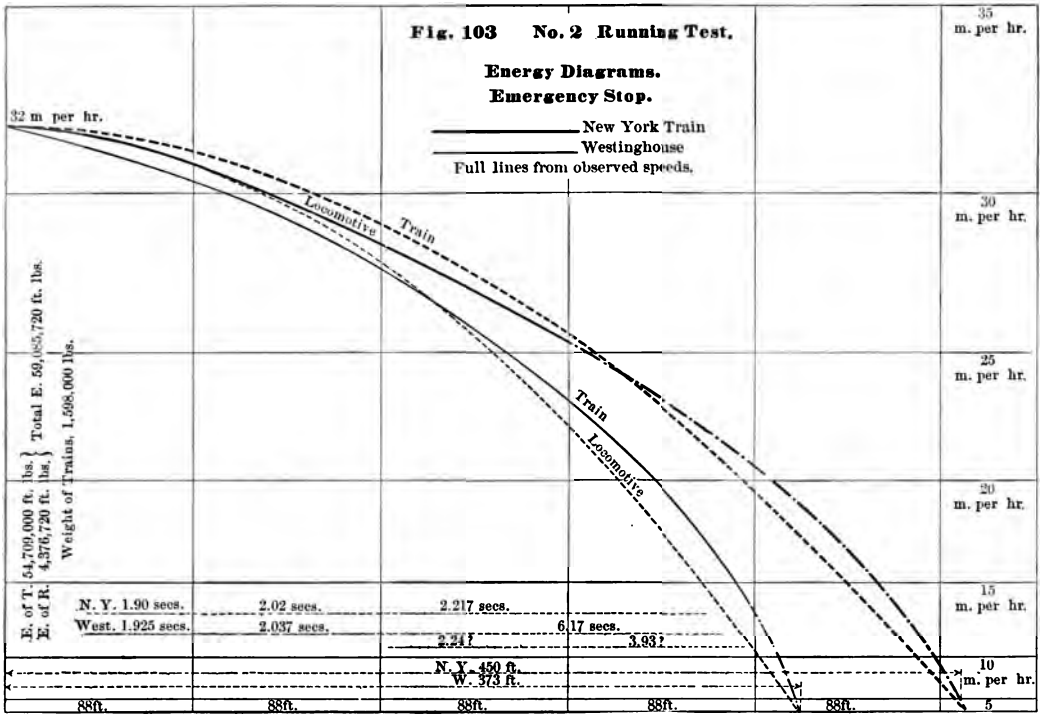


Fig. 103 No. 2 Running Test.
Energy Diagrams.
Emergency Stop.
New York Train
Westinghouse
Full lines from observed speeds.
32 m per hr.
Locomotive
Train
Train
Locomotive
Total E. 59,085,720 ft. lbs.
Weight of Trains, 1,598,000 lbs.
E. of T. 54,709,000 ft. lbs.
E. of R. 4,376,720 ft. lbs.
N. Y. 1.90 secs.
West. 1.925 secs.
2.02 secs.
2.037 secs.
2.217 secs.
6.17 secs.
3.93 ?
N. Y. 450 ft.
W. 573 ft.
88ft.
88ft.
88ft.
88ft.
88ft.
35 m. per hr.
30 m. per hr.
25 m. per hr.
20 m. per hr.
15 m. per hr.
10 m. per hr.
5

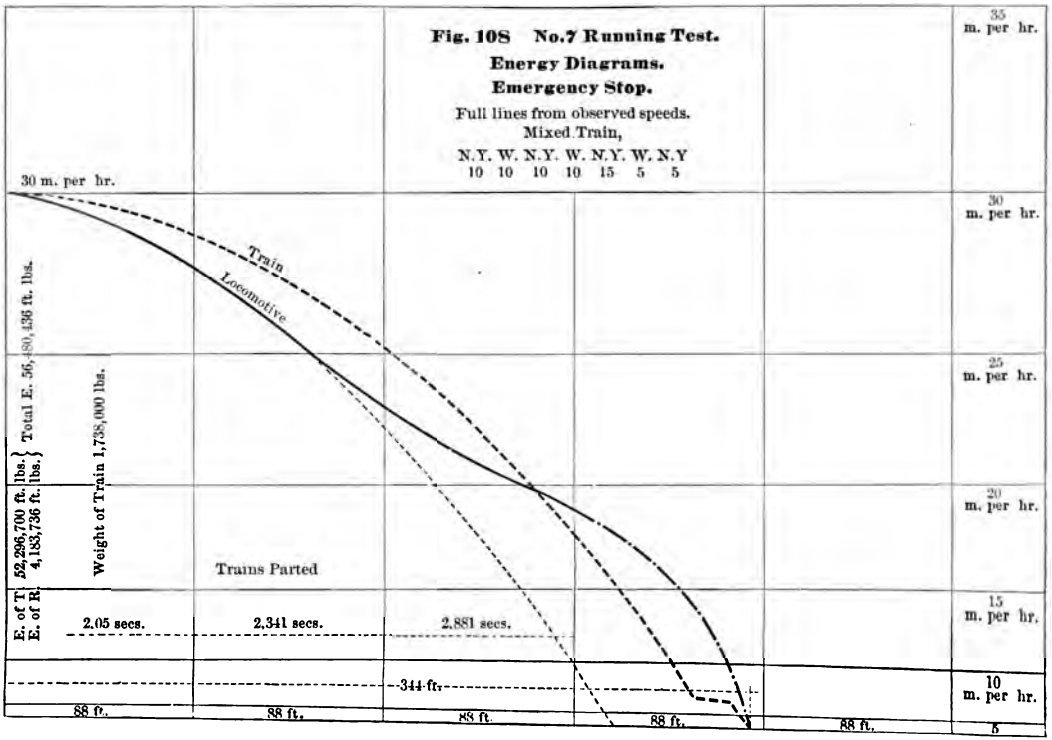


Fig. 108 No.7 Running Test.
Energy Diagrams.
Emergency Stop.
Full lines from observed speeds.
Mixed Train,
N.Y. W. N.Y. W. N.Y. W. N.Y
10 10 10 10 15 5 5
30 m. per hr.
35 m. per hr.
30 m. per hr.
25 m. per hr.
20 m. per hr.
15 m. per hr.
10 m. per hr.
5
Train
Locomotive
Total E. 56,480,436 ft. lbs.
Weight of Train 1,738,000 lbs.
E. of T. 52,296,700 ft. lbs.
E. of R. 4,183,736 ft. lbs.
Trains Parted
2.05 secs.
2,341 secs.
2,881 secs.
344 ft.
88 ft.
88 ft.
88 ft.
88 ft.
88 ft.

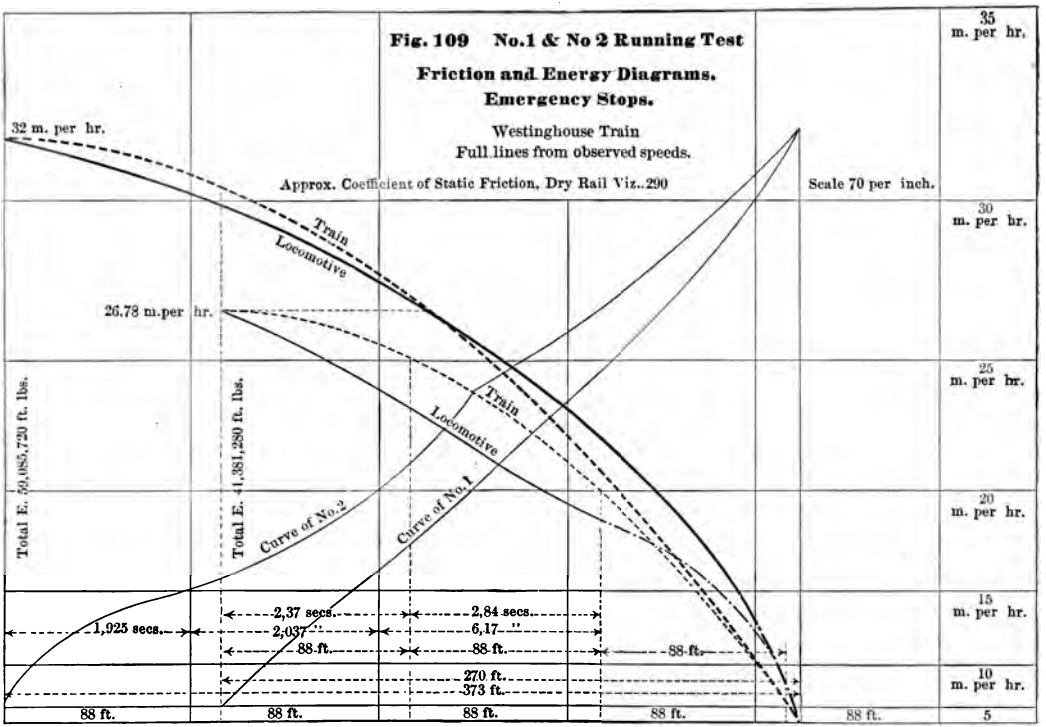


Fig. 109 No.1 & No 2 Running Test
Friction and Energy Diagrams.
Emergency Stops.
Westinghouse Train
Full lines from observed speeds.
Approx. Coefficient of Static Friction, Dry Rail Viz..290
Scale 70 per inch.
32 m. per hr.
26.78 m.per hr.
Train
Locomotive
Train
Locomotive
Curve of No.2
Curve of No.1
Total E. 59,085,720 ft. lbs.
Total E. 41,381,280 ft. lbs.
1,925 secs.
2,37 secs.
2,037 "
88 ft.
2,84 secs.
6,17 "
88 ft.
88 ft.
270 ft.
373 ft.
88 ft.
88 ft.
88 ft.
88 ft.
88 ft.
35 m. per hr.
30 m. per hr.
25 m. per hr.
20 m. per hr.
15 m. per hr.
10 m. per hr.
5

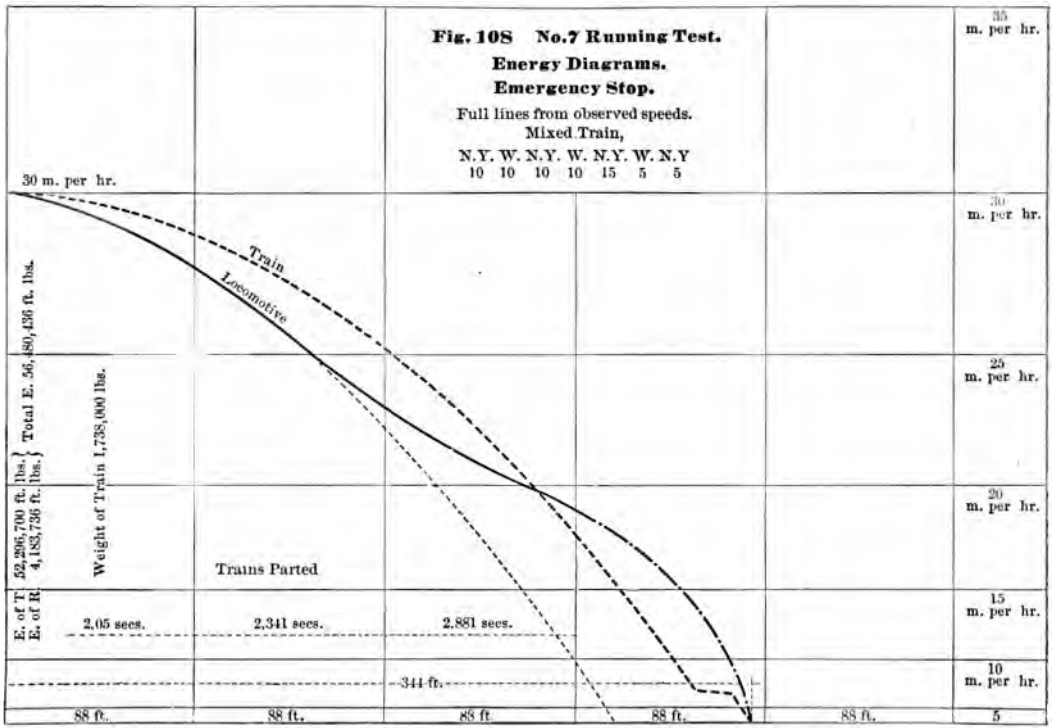


Fig. 108 No.7 Running Test.
Energy Diagrams.
Emergency Stop.
Full lines from observed speeds.
Mixed Train,
N.Y. W. N.Y. W. N.Y. W. N.Y
10 10 10 10 15 5 5
30 m. per hr.
Train
Locomotive
Total E. 56,480,436 ft. lbs.
Weight of Train 1,738,000 lbs.
E. of T. 52,296,700 ft. lbs.
E. of R. 4,183,736 ft. lbs.
Trains Parted
2.05 secs.
2.341 secs.
2.881 secs.
344 ft.
88 ft.
88 ft.
88 ft.
88 ft.
88 ft.
35 m. per hr.
30 m. per hr.
25 m. per hr.
20 m. per hr.
15 m. per hr.
10 m. per hr.
5

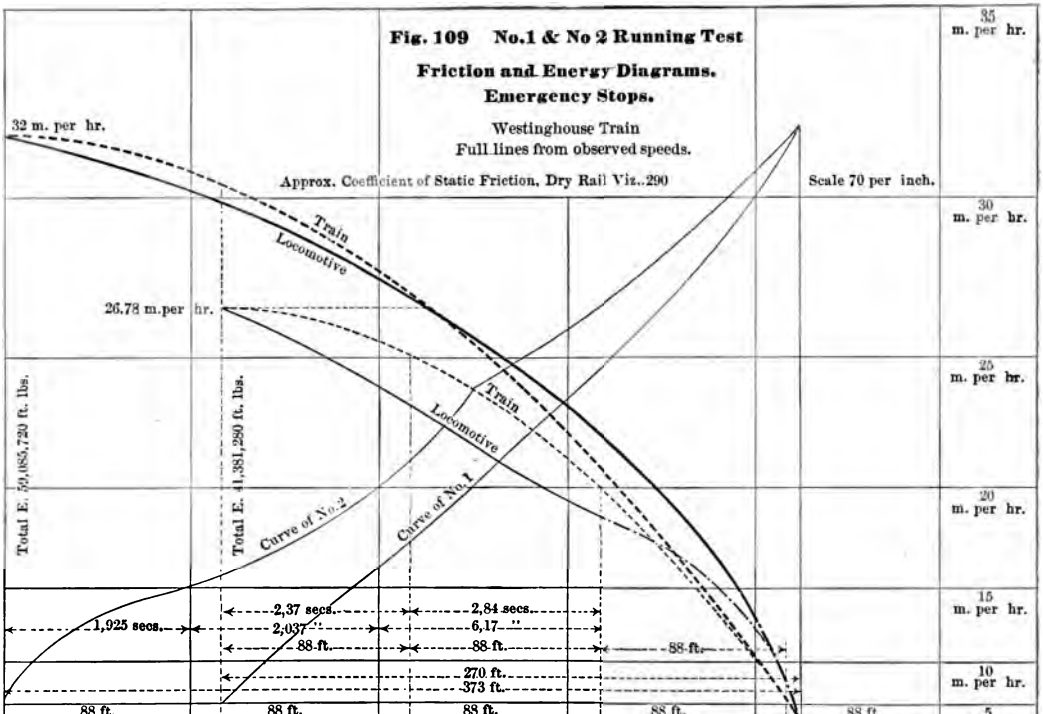


Fig. 109 No.1 & No 2 Running Test
Friction and Energy Diagrams.
Emergency Stops.
Westinghouse Train
Full lines from observed speeds.
Approx. Coefficient of Static Friction, Dry Rail Viz..290
Scale 70 per inch.
32 m. per hr.
26.78 m.per hr.
Train
Locomotive
Train
Locomotive
Total E. 59,085,720 ft. lbs.
Total E. 41,381,290 ft. lbs.
Curve of No.2
Curve of No.1
1,925 secs.
2,037 "
2,37 secs.
88 ft.
2,84 secs.
6,17 "
88 ft.
88 ft.
270 ft.
373 ft.
88 ft.
88 ft.
88 ft.
88 ft.
88 ft.
35 m. per hr.
30 m. per hr.
25 m. per hr.
20 m. per hr.
15 m. per hr.
10 m. per hr.
5

shocks on the fiftieth car on the Westinghouse train as observed with special electrical apparatus.

Trial No. 1, interval after application first car to application fiftieth car, 2.45 seconds.

Trial No. 1, interval after application first car to shock fiftieth car, 5.70 seconds.

Trial No. 2, interval after application first car to application fiftieth car, 2.68 seconds.

Trial No. 2, interval after application first car to shock fiftieth car, 5.73 seconds.

Trial No. 4, interval after application first car to application fiftieth car, 2.41 seconds.

Trial No. 4, interval after application first car to shock fiftieth car, 4.94 seconds.

NOTE. — Trial No. 3 was lost.

TABLE XXXVI.

Comparisons of "Galtons Table No. X," by the distance run in feet after five second intervals showing reductions of coefficient of friction.

Speed and Coefficient.	Five Seconds.	Ten Seconds.	Fifteen. Seconds.	Twenty Seconds.
20 miles	147 feet	294 feet	441 feet	588 feet
.182	.152	.133	.118	.099
Reduction	.030	.019	.015	.019
27 miles	198 feet	396 feet	594 feet	792 feet
.171	.130	.119	.081	.072
Reduction	.041	.011	.038	.009
37 miles	272 feet	544 feet	816 feet	. . . .
.152	.096	.083	.069	. . . .
Reduction	.056	.013	.014	. . . .
47 miles	345 feet	691 feet	. . . .	. . . .
.132	.080	.070	. . . .	. . . .
Reduction	.052	.010	. . . .	. . . .
60 miles	440 feet	880 feet	. . . .	. . . .
.072	.063	.058	. . . .	. . . .
Reduction	.009	.005	. . . .	. . . .

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No instrument was prepared to measure the time of the shocks in the New York train, but the observer for the fiftieth car said it occurred about as soon as they could get braced for it after feeling the brakes apply.

These trials showed that, within the practical limits of applying air to the train, the shocks were rendered so small as to be of no moment.

The Coefficient of Friction.

The trials at Karner indicated that the distance run after the shoes were applied was quite as important a factor as time in reducing the coefficient of dynamic friction.

Table XXXVII.

Trial.	Westinghouse Train.				New York Train.			
No. 1	26.78	miles to	25.1	.057	26.78	miles to	26.30	.049
	25.1	do.	20.1	.148	26.30	do.	24.40	.062
	20.1	do.	5.8	.249	24.40	do.	19.30	.148
	5.8	do.	0.0	.322	19.30	do.	7.20	.206
					7.20	do.	0.00	.313
No. 2	32.00	miles to	30.6	.057	32.00	miles to	31.00	.039
	30.0	do.	27.8	.107	31.00	do.	29.00	.080
	27.8	do.	22.5	.186	29.00	do.	25.50	.124
	22.5	do.	10.8	.255	25.50	do.	19.60	.175
	10.8	do.	0.0	.321	19.60	do.	7.50	.215
					7.50	do.	0.0	.324
No. 3	34.48	miles to	33.6	.039	34.48	miles to	33.60	.039
	33.6	do.	31.6	.084	33.60	do.	31.70	.081
	31.6	do.	27.4	.164	31.70	do.	28.30	.134
	27.4	do.	20.8	.201	28.30	do.	22.40	.192
	20.8	do.	5.0	.267	22.40	do.	12.20	.230
	5.0	do.	0.0	.320	12.20	do.	5.00	.276
					5.00	do.	0.00	.320

As the coefficient of static friction appears to be practically constant at different speeds, the constant brake-shoe pressure in the trials caused the coefficient of dynamic friction to be a very small percentage of the static coefficient at higher speeds.

The approximate percentages of the coefficient of static friction

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realized by the coefficient of dynamic friction at Karner trials Nos. 1, 2, and 3 for each train are given below.

Approximate curves from some of the above figures were plotted upon the diagrams, Figs. 109 and 110, and indicate some of the many complicated phases of the brake problem. The vertical height of the curve represents the percentage of the static coefficient that is obtained by the dynamic coefficient at the speed shown by the retardation curves above, and at the proportion of stop shown by the horizontal scale in feet.

With the M. C. B. standard of 70 per cent. of the weight of the empty freight cars as pressure on the brake shoes, even after the air was fully applied, nowhere near the full value of the coefficient of static friction was realized until near the stop.

The coefficient of static friction with a dry rail has a safe working value of .290 for the weight of the empty cars used in these trials, and on the energy diagrams were approximately represented by the line marked 30 miles per hour. The space below that line to the curve obtained shows the possibilities of practice — the length of stop being correspondingly reduced. For a "moist, slimy" rail the coefficient reduces to about .200; the line marked 25 miles per hour approximately represents the working limit of static friction.

Conclusions.

Referring to table No. IX. (The Galton Trials), giving the approximate coefficients of dynamic friction at different speeds, it will be readily seen that to utilize more nearly the full value of the coefficient of static friction for the fastest passenger trains and loaded freight trains, the brake shoe pressure must be largely increased, at high speeds, reducing as the speed decreases.

The curves indicated that at 60 miles per hour the brake shoe pressure could be doubled, reducing to about 1½ times at 40 miles and to the ordinary for the stop.

For heavy or high speed trains, the energy to be destroyed is so great that the brake mechanism must not only be efficient but ample to bring

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the train under control in emergencies from the distant to the home signal.

The trials at Karner also showed the increase in coefficient of friction due to time of application. This feature, and the rear unbraked cars running up against the front braked ones, seem to have modified the mean curves of realized static friction, so that the curves are not continuous but have two branches, the least modification from a continuous curve being in the shortest stops. This will be noticed in the friction diagrams, Figs. 109 and 110.

The locomotive had the air applied the full time, the next car a fraction of a second shorter, and so on for each car, the time reducing to about 8.5 seconds on the fiftieth car. The curve of friction for the front and rear cars of each train would be quite similar to those shown in the diagram in Fig. 109, the curve for the front cars corresponding to the curve for No. 2 trial, and for the rear cars to the curve of No. 1, the quickness and intensity of action increasing from the front to the rear of the train. The strains thus induced or grouped had to be equalized by the draft rigging, which broke in each train for all emergency stops after the second trials.

Examinations under the microscope of the surface of a few of the worn cast-iron shoes showed in general abrasion at all speeds, but they indicated at high speeds a wearing away of the metal by flowing off and reducing to thin flakes, some portions attaching and filling interstices made in preceding stops, others detaching in small particles; while at slow speeds, especially near the stop, the metal seemed to be torn out in larger particles, scoring deeper and producing an effect similar to that of sanding the shoe, though in a less degree.

The M. C. B. Association recommendations of tests for standard air brakes did not state whether the time interval of 3½ seconds from the first to the fiftieth car, and 55 lbs. pressure in the latter, should be measured on a 50-car train, either standing, running, or on a rack. The time obtained from rack tests, 6-in. piston travel, indicated .3 of a second less than obtained in the standing tests.

In the time of applying the air to the entire train, the tests at Karner indicated the great advance made in braking over the experi-

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ments at Burlington in 1886 and 1887. In 1886, on a 50-car train, 13 seconds was the time reported for the air to apply on only the twenty-fifth car; and in 1887, with improved valves, 4¼ seconds. At Karner, Nos. 1 and 2 trials, the air was applied and the train stopped in 11 and 12 seconds, respectively; the air being fully on one train in less than 4 seconds.

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In the summer of 1900 a very extensive series of tests were made by the Pennsylvania Railroad Company on their West Penn Sang Hollow extension, just east of Bolivia, Pa.

The principal question that was to be decided by these tests was the advisability of operating air brake equipments of the Westinghouse Air Brake Company and of the New York Air Brake Company in the same train. It is a well-known fact that whereas the construction of the triple valves of these two makes of brakes very closely resemble each other in principle, their action in emergency application is quite different, due to difference in construction and operation, so that in making certain kinds of stops the behavior of the brake for this reason is different, and the question was brought up whether the two could be operated in the same train with safety and reliability.

The Pennsylvania Railroad determined to settle this question for themselves, and obtained from both of the above-mentioned companies fifty of their then standard freight triple valves and made a thorough series of tests upon a 50-car freight train with, first, all of the cars light, and, second, with 48 out of the 50 cars loaded as far as possible with just 80,000 lbs. of pig iron. As the loaded train tests may be considered of more importance from a practical point of view, the results of these alone are given herewith and the conclusions based upon them.

The portion of track selected on the Sang Hollow division was practically level and free from such curves as would impose disturbing elements in the results of the test. It was carefully divided off into certain equal distances, stakes driven beside the track at each point, in order to determine the speed of the train when the brake was applied, and the distance run during the stop. These stakes were placed 100 feet apart and were so distributed that 88 stakes were passed before reaching the tripping point for automatically setting the brake, and were carried beyond this point for 3,500 feet. The usual electrical mechanisms for measuring speed and time were employed, and both standing and running tests were made to determine the rapidity and

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power of application quite similarly to those just described in the Karner tests. In the present trials the number of different tests were much larger than in the Karner trials and covered a wider range of variations in make-up of train. No official report of these tests was ever published and consequently the description herewith gives simply the results in tabulated form, without entering into any details of each test.

As mentioned above, 48 of the 50 cars were loaded; the first and fiftieth were light and used for the purpose of making records of the tests. Gauges were connected to the trainpipe, and to the reservoir, and also to the cylinder in the first, twenty-fifth, and fiftieth cars; in the latter was also placed a slideometer.

The runs were divided into three series; first, with the New York triple valves; second, with various mixtures in the same train; third, with the train equipped throughout with the Westinghouse triple valves. Each of these series were to be run at two speeds, viz.: 20 and 35 miles per hour. The trainpipe pressure throughout was 70 lbs. The gauges used in the engines and on the reservoir and trainpipe of the first car were tested every day and a correct table kept covering the day's run. Before starting each day, the trainpipe was tested to determine leakage, and the piston travel throughout the train was noted. This latter was adjusted to be not less than 5½ inches nor more than 6½ inches.

Stops were made with the following different applications of brakes: 1st, emergency; 2d, full service; 3d, 6 lb. service reduction; 4th, emergency following 6 lb. service reduction. The emergency proceded by a 6 lb. service application was arranged for the preliminary service reduction to occur at the following distances in feet before passing the trip to apply the emergency: 100, 150, 200, 250, 300, and 900.

After the above series were completed, a supplementary series was added using 90 lbs. trainpipe pressure. This series was run with emergency application, full service application and emergency preceded by 6 lb. service reduction at 300 ft. The emergency and full service

TABLE No. XXXVIII.

Arrangement of Brakes.	Character of Application.	Trainpipe Pressure.	Speed, Miles per Hour.	Distance.		
				Measured.	At 20 Miles per Hour.	At 35 Miles per Hour.
Westinghouse	Emergency	70	20.9	391	360	. . .
do.	do.	70	21.1	388	351	. . .
New York	do.	70	21.4	451	397	. . .
do.	do.	70	20.8	425	395	. . .
Westinghouse	do.	70	34.1	1,074	. . .	1,129
do.	do.	70	34.4	1,151	. . .	1,190
New York	do.	70	32.1	1,164	. . .	1,376
do.	do.	70	33.6	1,227	. . .	1,328
25 W., 25 N. Y.	do.	70	20.7	413	387	. . .
do.	do.	70	20.6	402	380	. . .
25 N. Y., 25 W.	do.	70	20.1	420	416	. . .
do.	do.	70	21.3	472	419	. . .
25 W., 25 N. Y.	do.	70	33.9	1,182	. . .	1,257
do	do.	70	35.1	1,285	. . .	1,278
25 N. Y., 25 W.	do.	69.5	34.7	1,331	. . .	1,344
do.	do.	70	35.3	1,385	. . .	1,302
Westinghouse	Full Service	70	20.1	1,104	1,096	. . .
New York	do.	70	19.9	1,103	1,111	. . .
Westinghouse	do.	70	34.1	2,478	. . .	2,584
New York	do.	70	33.3	2,379	. . .	2,570
25 W., 25 N. Y.	do.	70	21.3	1,239	1,131	. . .
25 N. Y., 25 W.	do.	70	23.9	1,473	1,129	. . .
25 W., 25 N. Y.	do.	70	34.9	2,604	. . .	2,616
25 N. Y., 25 W.	do.	70	34.4	2,618	. . .	2,692
Westinghouse	Emergency, preceded by 6-lb. service at 900 ft.	70	20.4	368	355	. . .
do.	do. do.	70	20.2	361	354	. . .
New York	do. do.	70	20.5	481	461	. . .
do.	do. do.	70	20.1	425	421	. . .
Westinghouse	do. do.	70	31.9	964	. . .	1,153
do.	do. do.	70	33.9	1,122	. . .	1,194
New York	do. do.	70	33.4	1,224	. . .	1,332
do.	do. do.	70	34.2	1,350	. . .	1,408
25 W., 25 N. Y.	do. do.	70	21.2	404	364	. . .
do.	do. do.	70	21.3	415	370	. . .
25 N. Y., 25 W.	do. do.	70	24.1	674	488	. . .
do.	do. do.	70	19.9	463	467	. . .
25 W., 25 N. Y.	do. do.	70	34.6	1,234	. . .	1,261
do.	do. do.	70	34.3	1,206	. . .	1,253
25 N. Y., 25 W.	do. do.	70	33.5	1,276	. . .	1,382
do.	do. do.	70	29.9	989	. . .	1,313
19 W., 4 N. Y., 27 W.	do. do.	70	21.1	429	390	. . .
do.	do. do.	70	20.4	400	386	. . .
19 N. Y., 4 W., 27 N. Y.	do. do.	70	20.3	456	445	. . .
do.	do. do.	70	19.2	391	418	. . .
29 W., 4 N. Y., 17 W.	do. do.	70	33.0	1,106	. . .	1,237
do.	do. do.	70	34.5	1,228	. . .	1,262
29 N. Y., 4 W., 17 N. Y.	do. do.	70	34.1	1,369	. . .	1,436
do.	do. do.	70	33.8	1,335	. . .	1,423

TABLE No. XXXVIII.— *Continued.*

Arrangement of Brakes.	Character of Application.	Trainpipe Pressure.	Speed, Miles per Hour.	Distance.		
				Measured.	At 20 Miles per Hour.	At 35 Miles per Hour.
3 W., 3 N. Y., 22 W., 22 N. Y.	Emergency, preceded by 6-lb. service at 900 ft.	70	21.7	441	380	. . .
do. do.	do. do.	70	21.3	412	367	. . .
3 N.Y., 3 W., 22 N.Y., 22 W.	do. do.	70	19.1	383	413	. . .
do. do.	do. do.	70	20.3	459	448	. . .
3 W., 3 N. Y., 22 W., 22 N. Y.	do. do.	70	32.9	1,126	. . .	1,267
do. do.	do. do.	70	34.0	1,197	. . .	1,265
3 N.Y., 3 W., 22 N.Y., 22 W.	do. do.	70	33.4	1,257	. . .	1,368
do. do.	do. do.	70	33.6	1,324	. . .	1,426
Westinghouse . .	Emergency, preceded by 6-lb. service at 300 ft.	70	21.3	420	373	. . .
New York . . .	do. do.	70	19.9	488	492	. . .
25 W., 25 N. Y. .	do. do.	70	21.0	439	402	. . .
25 N. Y., 25 W. .	do. do.	70	20.1	512	508	. . .
19 W., 4 N. Y., 27 W.	do. do.	70	21.1	488	433	. . .
19 N.Y., 4 W., 27 N.Y.	do. do.	70	20.2	565	555	. . .
10 W., 10 N.Y., 15 W., 15 N. Y.	Emergency, preceded by 6-lb. service at 100 ft.	70	19.9	390	394	. . .
10 N. Y., 10 W., 15 N. Y., 15 W.	do. do.	70	20.1	518	514	. . .
10 W., 10 N. Y., 15 W., 15 N. Y.	Emergency, preceded by 6-lb. service at 150 ft.	70	21.1	569	518	. . .
10 N. Y., 10 W., 15 N. Y., 15 W.	do. do.	70	20.4	529	511	. . .
10 W., 10 N. Y., 15 W., 15 N. Y.	Emergency, preceded by 6-lb. service at 200 ft.	70	20.4	496	479	. . .
10 N. Y., 10 W., 15 N. Y., 15 W.	do. do.	70	20.8	533	498	. . .
10 W., 10 N. Y., 15 W., 15 N. Y.	Emergency, preceded by 6-lb. service at 250 ft.	70	22.2	473	395	. . .
10 N. Y., 10 W., 15 N. Y., 15 W.	do. do.	70	20.0	512	(389) 512	. . . . .
10 W., 10 N. Y., 15 W., 15 N. Y.	Emergency, preceded by 6-lb. service at 350 ft.	69.5	19.5	421	438	. . .
10 N. Y., 10 W., 15 N. Y., 15 W.	do. do.	70	19.6	464	480	. . .
Westinghouse . .	Emergency	90	34.7	935	. . .	951
New York . . .	do.	90	34.6	1,024	. . .	1,047
Westinghouse . .	Full Service	90	33.2	2,064	. . .	. . .
New York . . .	do.	90	33.8	2,170	. . .	. . .
Westinghouse . .	Emergency, preceded by 6-lb. service at 300 ft.	90	22.2	367	. . .	. . .
New York . . .	do. do.	90	20.4	424	. . .	. . .
25 W., 25 N. Y. .	do. do.	90	20.2	347	. . .	. . .
25 N. Y., 25 W. .	do. do.	90	19.8	411	. . .	. . .
19 W., 4 N. Y., 27 W.	do. do.	90	20.0	373	. . .	. . .
19 N.Y., 4 W., 27 N.Y.	do. do.	90	20.1	426	. . .	. . .

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applications in this series alone was run at 35 miles per hour and the balance in 20 miles per hour.

All but two of the tests are recorded as having been made with the intended trainpipe pressure, so that the complications that might arise from variations in this pressure are almost entirely eliminated. Each length of stop was corrected from variations of speed from that intended and the results of the various tests are given herewith in table No. XXXVIII.

In making the corrections for distances traveled by the train at the observed speed, the distances were assumed to vary inversely as the square of the speed. Corrections in distances on account of variations in cylinder pressure were made on a basis that the distance traveled is inversely as the mean cylinder pressure. As stated before, this correction was practically eliminated in reference to the stops under consideration, due to the fact that the trainpipe pressure was, generally speaking, very closely to that desired. For the sake of comparison the data in the foregoing table was segregated according to the applications of the brake, thus showing more clearly the effect produced by an intermixture of the two systems.

Emergency Application.

The results found for the emergency stops made with a trainpipe pressure of 70 lbs., are shown in table No. XXXIX.

TABLE XXXIX.

Arrangement of Brakes.	20 Miles per Hour. Distance, Feet.	35 Miles per Hour. Distance, Feet.
50 Westinghouse	355.5	1159.5
50 New York	396.	1352.
25 Westinghouse 25 New York	383.5	1267.5
25 New York 25 Westinghouse	417.5	1353.

In the above table the stops at 35 miles per hour were somewhat unsatisfactory since the mean stop of the Westinghouse and New York

brakes each alone was an average of two runs only, one of which exceeded the other by about 5%. The relative length of stops, therefore, for this speed are not altogether reliable and too much importance should not be attached to them. This is to be regretted as this feature of the tests was one of the most important for satisfactory determination and should have been represented by the average results of a large number of stops.

Full Service Application.

Only one stop of each kind was made for this series, so that a comparison of results is useless, and a separate table of this application is omitted.

Emergency, Preceded by 6-lb. Service Application at 900 Ft.

It was intended that the preliminary service application should be made with a 6-lb. trainpipe reduction in all these tests. This reduction, however, varied considerable, although it averaged about 6 lbs. As a result of these variations, the cylinder pressure, due to the preliminary application, varied also. The results of these tests are given in the following table:

TABLE XL.

Arrangement of Brakes.	20 Miles per Hour. Distance, Feet.	35 Miles per Hour. Distance, Feet.
50 Westinghouse	354.5	1173.5
50 New York	441.	1370.
25 Westinghouse, 25 New York	367.	1257.
25 New York, 25 Westinghouse	477.5	1347.5
19 W., 4 N. Y., 27 W.	388.	. . .
19 N. Y., 4 W., 27 N. Y.	431. 5	. . .
29 W., 4 N. Y., 17 W.	. . .	1249.5
29 N. Y., 4 W., 17 N. Y.	. . .	1424.5
3 W., 3 N. Y., 22 W., 22 N. Y.	373.5	1266.
3 N. Y., 3 W., 22 N. Y., 22 W.	430.5	1397.

In each stop made with 3 Westinghouse brakes, followed by 3 New York, and then 22 Westinghouse, followed by 22 New York, the emergency jumped the 3 New York brakes, so that quick action occurred in all Westinghouse brakes, but on none of the New York brakes. No

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other case occurred in any of the tests where quick action in the Westinghouse brakes was not interrupted and discontinued by following the intervening New York brakes. In stops where 25 Westinghouse brakes preceded 25 New York brakes, quick action occurred on all of the Westinghouse brakes, but on none of the New York brakes, thereby causing excessive shocks to the back end of the train.

Emergency Application Preceded by 6-lb. Application at 300 Ft.

These stops were all made for a speed of about 20 miles per hour. Only one stop was made with each combination of brakes, and the distances traveled cannot, therefore, be assumed with certainty. The results of these tests are given in Table No. XLI.

TABLE XLI.

Arrangement of Brakes.	Distance in Feet.
50 Westinghouse	373
50 New York	492
25 Westinghouse, 25 New York	402
25 New York, 25 Westinghouse	508
19 Westinghouse, 4 New York, 27 Westinghouse	443
19 New York, 4 Westinghouse, 27 New York	555

It will be observed in the above table that the length of stop where 25 Westinghouse preceded 25 New York brakes, was about 9% longer than for 50 Westinghouse brakes alone; whereas, where 19 New York brakes preceded 4 Westinghouse, and then 27 New York brakes followed, the length of stop was nearly 49% greater. In these tests the erratic behavior of the New York brakes, when in combination with the Westinghouse brakes, was very manifest. The character of the application throughout the train and the mean final cylinder pressure was the same where 50 New York brakes were used alone; where 25 New York preceded 25 Westinghouse, and where 19 New York were followed by 4 Westinghouse and 27 New York; but the length of stop for each of these combinations differed largely.

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Air Brake Tests

Emergency, Preceded by 6-Lb. Service Application at Various Short Distances.

All of the stops in this series were made at a speed of about 20 miles per hour, and the make-up of the train was in every case either 10 Westinghouse followed by 10 New York, 15 Westinghouse and 15 New York, or 10 New York followed by 10 Westinghouse, 15 New York and 15 Westinghouse. The results are shown in table No. XLII.

TABLE No. XLII.

Service Precedes Emergency.	Arrangements of Brakes.	Distance in Feet.
100 feet.	10 W., 10 N. Y., 15 W., 15 N. Y.	394
100 do.	10 N. Y., 10 W., 15 N. Y., 15 W.	514
150 do.	10 W., 10 N. Y., 15 W., 15 N. Y.	518
150 do.	10 N. Y., 10 W., 15 N. Y., 15 W.	511
200 do.	10 W., 10 N. Y., 15 W., 15 N. Y.	479
200 do.	10 N. Y., 10 W., 15 N. Y., 15 W.	498
250 do.	10 W., 10 N. Y., 15 W., 15 N. Y.	395 (389)
250 do.	10 N. Y., 10 W., 15 N. Y., 15 W.	512
350 do.	10 W., 10 N. Y., 15 W., 15 N. Y.	438
350 do.	10 N. Y., 10 W., 15 N. Y., 15 W.	480

The first stop shown in table No. XLII. was practically a regular emergency stop, since no triple valves of the New York Brakes had been acted upon by the service reduction of trainpipe pressure before the effect of quick action in the emergency application reached them. In all of the stops where New York brakes were in the lead, quick action failed to apply throughout the train similarly to the preceding series. Some very erratic features in the operation of the brakes was also noted in the stops of these series.

Conclusions.

Ordinary emergency stops were about 12% longer with the New York than with the Westinghouse brake equipment. In emergency stops preceded by service application, those made with the New York brakes were found to be from 17 to 32% longer than those made with

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the Westinghouse brakes, depending upon the conditions. Where the New York brakes were mixed with the Westinghouse, the operation of the combination was generally better than when the New York brakes were used alone, if the Westinghouse brakes are next the engine. When New York brakes were next to the engine, very erratic and incomprehensible action took place. In all cases of emergency preceded by service applications where New York brakes were so placed, the quick-action feature of both kinds of brakes was destroyed. What took place was a full service application under conditions which caused that application to be made very promptly and effectively. An emergency stop with the Westinghouse brakes, at a speed of 20 miles per hour, after a previous application at 100 ft., was made in a distance of 355 feet. With 10 New York brakes preceding 10 Westinghouse, 15 New York and 15 Westinghouse, the stop was 514 ft., 45% greater than the Westinghouse stop, where the service application preceded the emergency by 300 feet. The stop at 20 miles per hour, with 19 New York brakes, followed by 4 Westinghouse and 24 New York, exceeded the stop of 50 Westinghouse by 49%. Since many of these stops were single ones and not an average of a number of each kind, the above mentioned results cannot be assumed with certainty, but the results showed the erratic action of the brakes when the two systems are mixed together.

THE SHIPROAD TESTS.

These tests occurred in October, 1894, upon the main line of the Pennsylvania Railroad, just west of Philadelphia, and are chiefly interesting as being the first tests made upon what is known as the high-speed brake. Whereas the results may not have been as accurately obtained as those of subsequent trials, they showed most convincingly the great advantage of the high-speed apparatus, and were very useful in bringing to the attention of railways, as well as pointing out to the brake companies, such defects as may have been embodied in the primitive design of such auxiliary apparatus as went to make up this equipment.

The tests were made upon a train of locomotive and 6 passenger coaches, and were divided into two series made upon consecutive days. The first series was called the preliminary test, and included several runs, at speeds approximating 45 miles per hour. The trainpipe pressure was 70 lbs. for the ordinary quick-action brake, and 100 lbs. for the high-speed brake. The runs of the second day repeated those of the first, except that the speeds were raised to 60 miles per hour.

The grade of track at the point where the tests were made was 29 feet to the mile, descending. On both days the weather was fair and the rails dry. The braking-power percentage on the cars was obtained from indicator diagrams taken by instruments in each car. The total weight of the train was 564,000 lbs.

The results of the tests are given in the following tables. Test No. 1 of each series is omitted because of the figures being untrustworthy, due to trouble with the recording apparatus.

The average length of stop in feet from a speed of 45 miles per hour with 70 lbs., trainpipe pressure was 688.5. The average length of stop in feet from a speed of 45 miles per hour with 100 lbs., trainpipe pressure was 574. This gave a percentage in length of stop in favor of 100 lbs. trainpipe pressure as against 70 lbs. of 17%.

The average length of stop at 60 miles per hour at 70 lbs. trainpipe pressure was 1,620 ft. The average length of stop at 60 miles per hour with 100 lbs. trainpipe pressure was 1,329 ft., giving a percentage of average length of stop in favor of 100 lbs. as against 70 lbs.

THE SHIPROAD TESTS

trainpipe pressure, of 18%. The average length of stop with 109 lbs. trainpipe pressure was 1,167 ft., so that the percentage of length of stops in favor of 109 lbs. as against 70 lbs. trainpipe pressure was 28%.

TABLE XLIII. — PRELIMINARY TESTS OF OCTOBER 1, 1894, WITH HIGH-SPEED BRAKE TRAIN, CONSISTING OF LOCOMOTIVE AND SIX PASSENGER CARS.

Test Number.	Trainpipe Pressure: Pounds.	Actual Speed M. P. H.	Time Making Stops: Seconds.	Actual Length of Stop: Feet.	Braking Power on Engine and Tender: Per Centage.	Braking Power on Cars: Per Centage.	Total Braking Power on Train: Per Centage.	Calculated Length of Stop at 45 M. P. H., 70 Lbs. Trainpipe Pressure: Feet.	Calculated Length of Stop at 45 M. P. H., 100 Lbs. Trainpipe Pressure: Feet.
2	71	47¾	21	776	52.2	86.8	76.3	702	. .
3	69	45½	18½	697	52.	86.	75.7	675	. .
4	100	46¾	15½	584	76.2	102.5	94.5	. .	567
5	104	46¼	15½	610	75.4	106.4	97.	. .	600
6	100	47	15¼	601	77.1	105.	96.5	. .	555

TABLE XLIV. — TEST OF OCTOBER 2, 1894, WITH HIGH-SPEED BRAKE TRAIN, CONSISTING OF LOCOMOTIVE AND SIX PASSENGER CARS.

Test Number.	Trainpipe Pressure: Lbs.	Actual Speed M. P. H.	Time Making Stops: Seconds.	Actual Length of Stop: Feet.	Braking Power on Engine and Tender: Per Centage.	Braking Power on Cars: Per Centage.	Total Braking Power on Train: Per Centage.	Calculated Length of Stop at 60 M. P. H., 70 Lbs. Trainpipe Pressure: Feet.	Calculated Length of Stop at 60 M. P. H., 100 Lbs. Trainpipe Pressure: Feet.	Calculated Length of Stop at 60 M. P. H., 109 Lbs. Trainpipe Pressure: Feet.
2	68	60¾	31½	1,697	51.6	85.2	75.	1,618	. . .	. . .
3	71	61½	30½	1,634	52.	87.6	76.8	1,576	. . .	. . .
4	71	58¾	31	1,584	52.	87.	76.4	1,668	. . .	. . .
5	100	61¼	25	1,372	79.3	101.8	95.	. . .	1,319	. . .
6	104	61½	25½	1,361	79.8	100.6	94.3	. . .	1,344	. . .
7	105	61½	24	1,330	81.1	100.9	94.9	. . .	1,324	. . .
8	108	58¼	22	1,125	82.8	107.7	100.1	. . .	. . .	1,179
9	109	61¼	22½	1,202	83.2	108.	100.5	. . .	. . .	1,155

NASHVILLE LOCOMOTIVE BRAKE TESTS.

These tests were carried on upon the Nashville, Chattanooga & St. Louis Railway at Nashville, Tenn., under the supervision of the Assistant General Manager of that line and were reported by the Press and Printing Committee of the Air Brake Association in 1895. The tests were made for the purpose of ascertaining the difference in length of stop obtained if the engine was reversed when the air brakes were applied and the wheels locked, from that if the air brakes alone were used.

One of the locomotives of the road was especially equipped with the latest style of push-down cam brake having 75 per cent. braking power, and the engine was put into such good repair and condition that the desired data would be complete and reliable. The tests were carried on for six days, making nearly 100 runs, and the records given in the following table are averages taken from the total number.

DATA.— Braking power on driving wheels of locomotive, 70 per cent.; braking power on wheels of tender 100 per cent. of light weight; braking power on wheels of N. C. & St. L. coaches 90 per cent.; braking power on wheels of Pullman sleeping cars, varied from 40 per cent. to 101 per cent.

A trip was placed in the track to open the trainpipe. A second trip was used to open the signal pipe, thus giving the engineer a signal to reverse the engine simultaneously with the application of the air brakes. Engine was equipped with a Boyer speed recorder which was tested each day.

The following order of operation was followed: First, brake applied; second, engine reversed; third, sand lever opened.

Track was level, and in best possible condition.

Tests were made under the most favorable circumstances.

The deductions to be drawn from the tests may be summed up as follows:

First: — The shortest reliable stops will be made by retarding power which is most quickly developed and maintained to the highest possible limit during the entire stop, consistent with safety from skidding wheels, such as the air brakes give, and is confirmed by records in the following table:

TABLE SHOWING RESULTS OF TESTS MADE TO DETERMINE THE RELATIVE STOPPING POWER OF THE AIR BRAKES, ENGINE REVERSED WITHOUT BRAKES, AND AIR BRAKES WITH ENGINE REVERSED.

No.	Brakes Used.	Condition of Train.	Speed.	Sand.	STOPS.					Wheels Skid.	Flat Spots.
					Total No.	Maximum Length.	Minimum Length.	Average in Feet.	Time, Seconds.		
1	Driver and Tender Brakes	Engine and Tender	30	No	9	280	240	254	11	No	No
2	Driver Brake alone	do. do.	30	do.	2	438	387	412	18	do.	do.
3	Tender Brake alone	do. do.	30	do.	7	604	458	538	23	do.	do.
4	No Brakes, Engine Reversed	do. do.	30	do.	3	464	426	450	20	Locked and revolved backwards	do.
5	Driver and Tender Brakes and Engine Reversed	do. do.	30	do.	4	290	245	276	12	Yes	2 1/8
6	No Brakes and Engine "Plugged"	do. do.	30	do.	2	540	505	522	25	Locked and revolved backwards	No
7	Driver and Tender Brakes	do. do.	30	Abundance	1	260	260	260	11	No	do.
8	No Brakes and Engine Reversed	do. do.	30	do.	1	280	280	284	12	do.	do.
9	No Brakes and Engine "Plugged"	do. do.	30	do.	1	265	265	265	11	do.	do.
10	Driver and Tender Brakes and Engine Reversed	do. do.	30	No Fresh Sand	4	177	140	158	9	do.	do.
11	Driver and Tender Brakes, Engine "Plugged"	do. do.	30	do.	1	177	177	177	9	do.	do.
12	Driver and Tender Brakes	do. do.	20	No	1	111	111	111	8	do.	do.
13	No Brakes and Engine Reversed	do. do.	20	do.	1	161	161	161	9	do.	do.
14	Driver and Tender Brakes	do. do.	20	Yes	1	90	90	90	6	do.	do.
15	Driver and Tender Brakes	do. do.	40	No	1	532	532	532	25	do.	do.
16	No Brakes, Engine Reversed	do. do.	40	do.	2	861	820	840	32	Locked and revolved backwards	do.
17	Driver and Tender Brakes	do. do.	40	Yes	1	475	475	475	20	No	. . .
18	All Brakes cut in	Engine, Tender and 5 N. C. & St. L. Coaches	30	No	8	271	260	258	11	do.	do.
19	All Brakes cut in	do. do.	30	Yes	1	250	250	250	11	do.	do.
20	All Brakes cut in and Engine Reversed	do. do.	30	do.	7	335	199	265	11	Yes	3 in.
21	All Brakes cut in	do. do.	40	No	4	500	400	474	19	No	No
22	All Brakes cut in	do. do.	40	Abundance	1	475	475	475	19	do.	do.
23	All Brakes cut in and Engine Reversed	do. do.	40	Yes	1	542	542	542	23	Yes	4 in.
24	All Brakes cut in	Engine, Tender, 5 N. C. & St. L. Coaches and 4 Pullmans	30	No	1	327	327	327	14	No	No
25	All Brakes cut in	do. do.	35	do.	1	465	465	465	19	do.	do.
26	All Brakes cut in	do. do.	40	do.	2	575	575	575	25	do.	do.
27	All Brakes cut in	Engine, Tender, and 4 Pullman Sleepers	30	do.	1	367	367	367	14	do.	do.
28	All Brakes cut in	do. do.	40	do.	1	702	702	702	26	do.	do.
29	† All Brakes cut in and Engine Reversed	Engine, Tender, and 5 N. C. Coaches	30	Yes	9	375	218	350	13	Yes	2 3/4 in.
30	* All Brakes cut in and Engine Reversed	do. do.	30	do.	1	325	325	325	13	No	No
31	† All Brakes cut in and Engine Reversed	do. do.		do.	1	375	375	375	14	Yes	3 in.
32	Pullman Sleeper "Kicked"	. . . . .	30	No	1	416	416	416	18	No	No
33	N. C. & St. L. Coach "Kicked"	. . . . .	30	do.	1	202	202	202	10	do.	do.

† Unexpected Emergencies. * Expected Emergency.

NASHVILLE LOCOMOTIVE BRAKE TESTS

Second : — The retarding power given by the back pressure in the steam cylinders when the engine is reversed fluctuates and is too inconstant to be relied upon. As soon as the back pressure developed is greater than the adhesion between the wheel and the rail, the driving wheels will revolve backwards and lose all retarding force. Trials were made throwing the reverse lever ahead sufficient length of time to release the wheels and get them running forward again, but so much time and distance were lost in this effort that the stop exceeded in length that made by leaving the lever in the back motion after it had been placed there. The length of stop was the same, whether the cylinder cocks were opened or closed. When the engine was reversed without brakes the wheels did not lock rigidly.

Third : — The length of stop made with air brakes applied and engine reversed, while being longer and extremely injurious to the tire from skidding and making flat spots, is not as long as was expected, but is satisfactorily accounted for by the fact that as the flat spot grew during the stop, and, with the heat developed, gave a larger and better surface to the rail for adhesion. The stop was longer than those made with the brakes alone and was very costly. The results of these tests should determine the inadvisability of using the reverse lever in conjunction with air brakes.

Fourth : — Sand is a good thing if judiciously used, but if used after wheels are skidding will produce flat spots and will not unlock the wheels after they commence sliding. A superabundance of sand is not quite so effective as a moderate amount. The best results were had from a rail upon which sand remained from a previous stop.

Upon a rail thoroughly "saturated" but not burdened with sand, it was impossible to slide the wheels under the conditions which prevailed. On straight track, if sand reached the rail before full retarding power was developed by the air brake and the back pressure in the steam cylinders with engine reversed, wheels would not lock or slide ; but on curves where engine rolled about, the adhesion between the wheel and rail, even when increased by a free flow of sand, would be broken and the drivers would lock and slide with disastrous results.

Air Brake Tests

NASHVILLE LOCOMOTIVE BRAKE TESTS

Several of the "Unexpected Emergencies," as recorded in Nos. 29 and 31, were made on curves, but the majority were made on straight track. If sand valves were opened before brakes were applied and engine reversed, the wheels would not lock in "Expected Emergencies," but the delay in applying retarding power would slightly lengthen the stop over that had by the use of the air brakes alone.

Fifth: — In making the "Unexpected Emergency" stops the drivers would invariably lock when engine was reversed and flat stops were had. In one instance the engineer, who was unusually expert and active, got tangled up with the reverse lever and did not succeed in reversing the engine with his first effort. The train ran considerably farther than the length of stop given in No. 29. The time consumed by the engineer in applying brakes, reversing engine, and opening sand valves was 1½ seconds, which is very much quicker than the feat can be accomplished ordinarily. When also considering the fact that a certain length of time is consumed by the engineer recovering from the bewilderment of "Unexpected Emergencies," it would seem impossible for him to get sand on the rail before the wheels would lock if he were to reverse his engine after applying the brake. The "Expected Emergency" given in No. 30 was a good stop, but engineers seldom meet expected emergencies.

Sixth: — The Pullman cars were not braking as they should, as the piston travels on all cars varied from 10 to 12 inches. After the slack was taken up better stops were had. The percentage of braking power on these cars had an abnormally wide range. The condition of the brake apparatus on the N. C. & St. L. coaches, which were taken from service without any preparation for the test, speaks eloquently for the system of maintenance of brakes on the N. C. & St. L. R'y. Tests Nos. 32 and 33 were made by backing the car with the engine until the desired speed was developed, then the angle cock was closed, engine detached, and hose uncoupled. The angle cock was opened at a certain point, from which the stop was taken.

THE ABSECON TESTS.

The object of these tests was to obtain reliable data of the stopping power of the high-speed brake, as compared with the ordinary quick-action brake on passenger trains. In view of the fact that in previous trials speeds were not determined by accurate methods, it was decided that in making the present tests the following general method should be followed :

First :— Stops should be made on a practically level track ; the brakes to be always applied at the same point.

Second :— An accurate method should be used to record the speed of the train, not only at the moment of the brake application, but also during the whole stop, so as to determine the rate of retardation during the stops from different speeds.

Third :— That stops should be at progressive speeds, at as nearly as possible 20, 30, 40, 50, 60, 70, etc., miles per hour.

Fourth :— That the train should be variously made up, so as to represent as far as possible the different classes of trains used in actual service.

The trials were made on the Atlantic City division of the West Jersey & Sea Shore Railroad, on the long tangent which terminates near Absecon. All stops were made on the southbound track. The emergency applications were automatically made by a trip block placed beside the track at the zero point or trip. The stopping track was approximately level, but the approaching grades were, as a rule, in favor of the train attaining speed. Electric contact breakers were arranged to break and again make the circuit. The circuit breakers were placed in a series beginning 396 ft. in advance of the zero point or trip, and continuing 5,200 ft. after passing that point. Those in advance of the zero point were spaced 66 ft. apart, while those after passing the trip were spaced 100 ft. apart. In the same circuit with the breakers were the necessary batteries and two chronographs, each arranged to record on a paper-covered drum, revolving at a uniform rate, the time interval between the breaks in the track circuit. Accurate circuit breaking clocks recorded the time intervals on the same

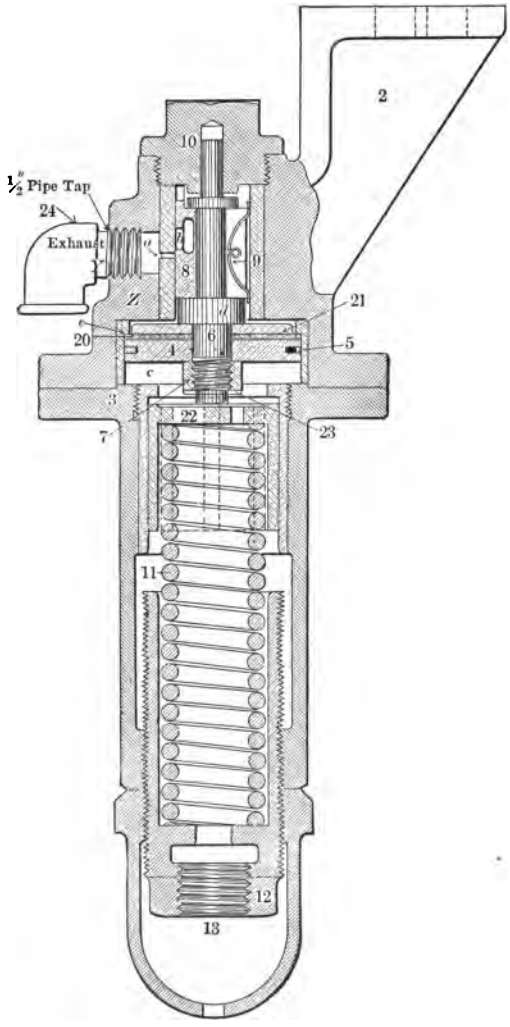

Fig. 111

Westinghouse High-Speed Brake Reducing Valve.

paper, so that the actual elapsed time between any two breaks could be directly measured.

As the train passed each circuit breaker a flexible wiper placed on the tender caused a break, and each of these breaks were instantly recorded by the chronographs. Thus by the time interval between passing the circuit breakers in advance of the zero point, the initial speed of the train before the brake application was determined, and its retardation during the stop was shown by the lengthening intervals of time required to pass each 100 ft. space.

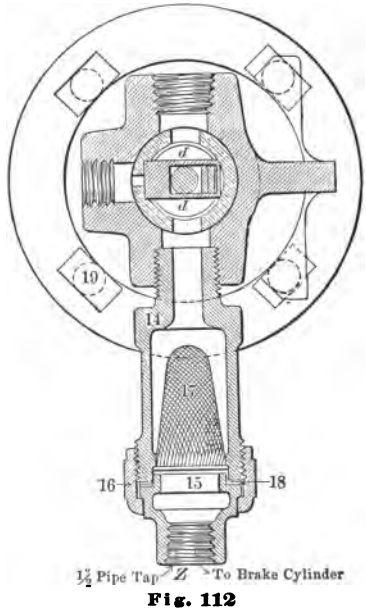

Fig. 112

In table XLV. will be found the weight of the engine on the truck and on the other wheels; also the weight of the tender ordinarily loaded, and of each car in the train, together with the percentage of weight on the rail which was braked.

The feature which distinguishes the high-speed brake from the ordinary quick-acting one, is the reducing valve shown in Figs. 111 and 112.

THE ABSECON TESTS

One such valve is attached to each brake cylinder. Its function is to allow a momentary increase of pressure over that which is permissible at the time of the stop; this pressure gradually leaking off.

As the tests were to prove the relative performance of the quick-acting brake, carrying 70 lbs. trainpipe pressure, and the high-speed brake, carrying 110 lbs. trainpipe pressure, at different speeds and with

TABLE XLV. — ARRANGEMENT AND WEIGHTS OF TRAINS AND AVERAGE PERCENTAGE OF BRAKING POWER.

Arrangement of Train.	Total Weight, Lbs.	Percentage of Weight Braked, M. E. P. in Cylinder.	
		58 Lbs.	88 Lbs.
Locomotive, 6 Coaches, and Chair Car	774,650	72.8	110.1
Locomotive and 6 Coaches	667,050	73.1	111.0
Six Coaches only	372,350	92.9	140.8
Locomotive, 3 Coaches, and Chair Car	588,700	66.1	100.4
Locomotive and 3 Coaches	481,100	65.5	99.4
Locomotive only	294,700	48.3	73.3

various arrangement of trains, the full programme was made of the tests proposed, and it was decided that the tests should be made at a series of progressive speeds, the same speeds, as far as practicable, being reached with each brake. The speeds desired were those commencing at 20 miles per hour and increasing by steps of 10 miles per hour, until the highest attainable one was reached.

The following arrangements of train were decided upon:

1. Locomotive, 6 coaches, and 1 chair car.
2. Locomotive and 6 coaches.
3. Locomotive, 3 coaches, and 1 chair car.
4. Locomotive and 3 coaches.
5. Locomotive alone.

The weights of each of these trains, and the percentage braked with

TABLE XLVI. — PERCENTAGES AND WEIGHTS BRAKED.

Locomotive and Coaches.

Vehicle.	Weight, Lbs.	Total Braking Power for 1 Lb. in Cylinder Lbs.	PERCENTAGE OF WEIGHT BRAKED.			WEIGHT BRAKED, LBS.	
			1 Lb. M. E. P.	58 Lbs. M. E. P.	88 Lbs. M. E. P.	58 Lbs. M. E. P.	88 Lbs. M. E. P.
Engine — Truck	36,650	7.50	1.028	59.6	90.5	21,844	33,168
Engine Drivers and Trailers	139,950	13.359	1.080	62.6	95.0	87,609	132,950
Engine — Total	176,600	20.859	1.064	62.0	94.0	109,492	166,004
Tender — Ordinary Load	118,100	7.195	0.481	27.7	42.0	32,714	49,602
Engine and Tender	294,700	28.054	0.832	48.3	73.3	142,166	216,015
Coach	62,350	8.728	1.583	91.8	139.3	57,240	86,855
do.	62,050	8.801	1.604	93.0	141.1	57,710	87,550
do.	62,100	8.973	1.634	94.7	143.0	58,809	88,820
do.	61,700	8.676	1.590	92.2	139.9	56,889	86,319
do.	62,150	8.740	1.590	92.2	139.9	57,305	86,949
do.	62,000	8.827	1.610	93.4	141.7	57,909	87,850
Pullman	107,600	8.302	1.188	68.9	104.5	74,136	112,550

THE ABSECON TESTS

the cylinder pressures attained in both the quick-acting and the high-speed brake, are shown in table XLVI.

An engine was taken from service and equipped with brakes on the trailing wheels in addition to those on the drivers and truck. By this arrangement the brakes on the drivers and trailers were equalized and operated by two 12-in. cylinders, but a separate cylinder, triple valve and reservoir were applied to the engine truck brake. The engine was also equipped with the trip cock used by the Westinghouse Air Brake Company for automatically venting the trainpipe during the emergency stops. A special trainpipe gauge was placed in the engine cab, as well as the recording voltmeter of an electric speed indicator. The tender was equipped with a high-speed reducing valve.

Each of the 6 coaches was equipped with a reducing valve suitable for a 12-in. cylinder. Five of the cars were furnished with brake cylinder pressure indicators, supplied by the Westinghouse Air Brake Company. These are simply steam engine indicators, in which the ordinary paper drum is replaced by a larger one driven by a clock escapement. The indicator cards show the pressure per square inch on the ordinates and the seconds on the abscissas. These five cars were also equipped with cylinder and reservoir gauges, and two of the cars with trainpipe gauges.

The Pullman car was equipped with a reducing valve, but not with any gauges or indicators. The brake equipment of the entire train was overhauled before trial, but, as it proved, some of the triple valves were not in the best possible condition. In this respect, the train fairly represented, as a whole, conditions which are readily duplicated in service. All the cars, as well as the tender, were equipped with the ordinary cast-iron brake shoes, which had been worn to a fair bearing before the trials began. The shoes which were worn out during the trials were replaced by others partly worn, to remove the hard external scale. The shoes on the engine were steel castings; those on the trailing wheels being new.

Owing to the presence of automatic signals, approximately 1 mile apart, the train was not allowed to back past any signal. It could,

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however, back about 2,000 ft. from the cabin, and in this distance it was possible to reach speeds of 20 and 30 miles per hour with the full train. Above these speeds it was necessary to cross over at Absecon and back on the northbound track to the point of starting. As a rule, 40 and 50 miles could be made from a distance of 1.2 miles; 60 and 70 miles from a distance of 3.8 miles, and 80 miles per hour from a distance of 9 miles, and the higher speeds from a distance of 15.1 miles.

It was decided that the acceleration at the start should be as rapid as possible, and steam was shut off in advance of reaching the marked track, so that the train, as nearly as possible, would drift at uniform speed, over the six spaces, each of 66 ft., in advance of the zero or trip point. At the trip point, the stop-block placed along the track struck the trigger which kept the emergency valve on the engine closed. This suddenly opened the trainpipe and made the emergency application. In service applications, the opening in this pipe was plugged, and the applications were made by hand in the usual manner.

The wiper on the tender struck each contact breaker as it passed; the circuit being immediately reëstablished, so that the breaks in the track circuit would be recorded on the chronograph drum in the cabin.

The braking power of the locomotive and tender was considerably lower than standard (unfortunately representing a condition which is very often met with in practice when the brakes are not carefully maintained). For that reason the percentage of braking power for the smaller trains was much less, the weight of the engine being a so much greater percentage of the total weight.

The Pullman car also happened to have a variation from the standard leverage, giving a much lower braking power on this car than is usual, the effect of which is so interestingly shown in the records. As the train was selected pretty much at random, in order to represent such conditions as might be met with in service, the leverages were allowed to remain as they were found.

The results have been arranged as shown in the accompanying curves and tables.

Fig. 113 shows the velocity curves from the moment that the brake

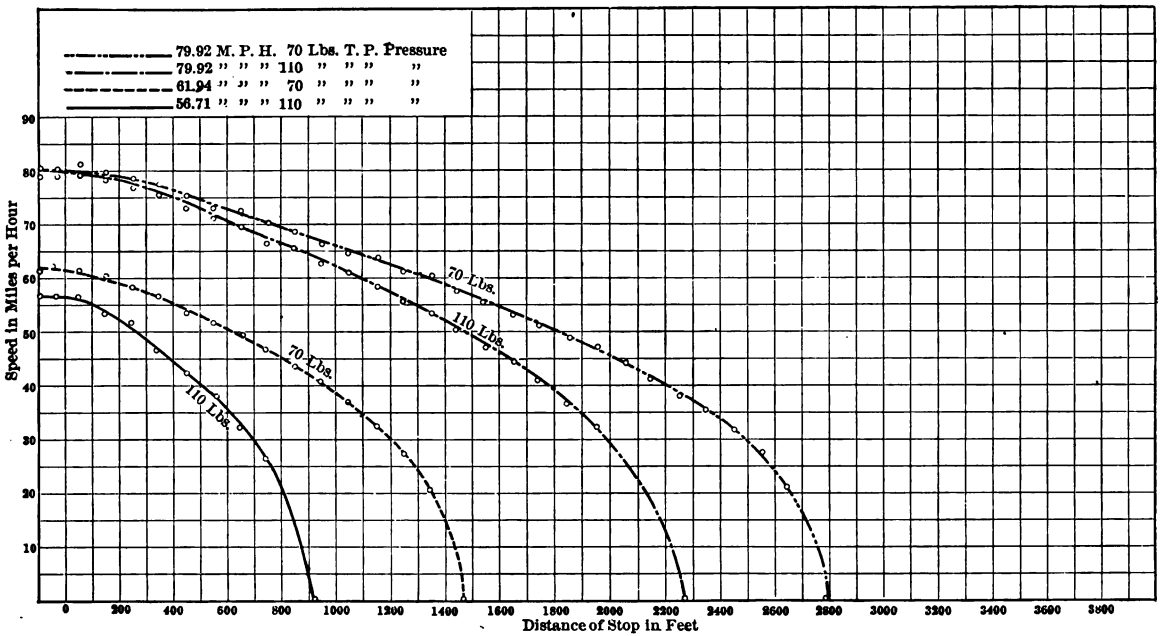

Fig. 113 Curve of Velocities from Moment of Application of Brakes, for Train of Engine, Six Coaches, and Chair Car.

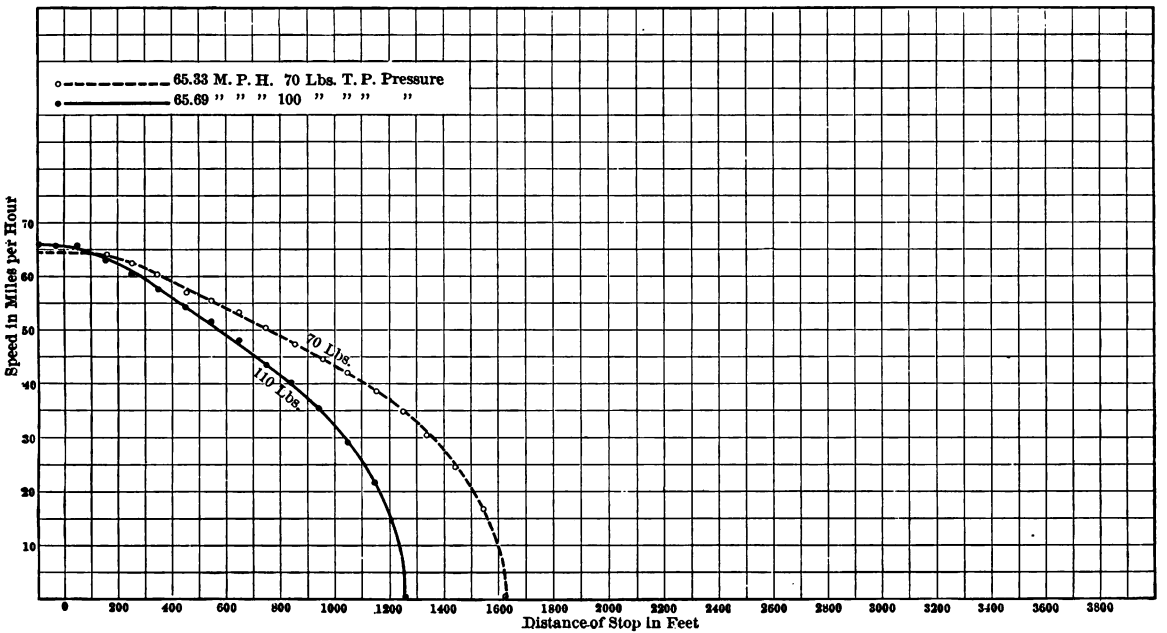

Fig. 114 Curve of Velocities from Moment of Application of Brakes, for Train of Engine and Six Coaches.

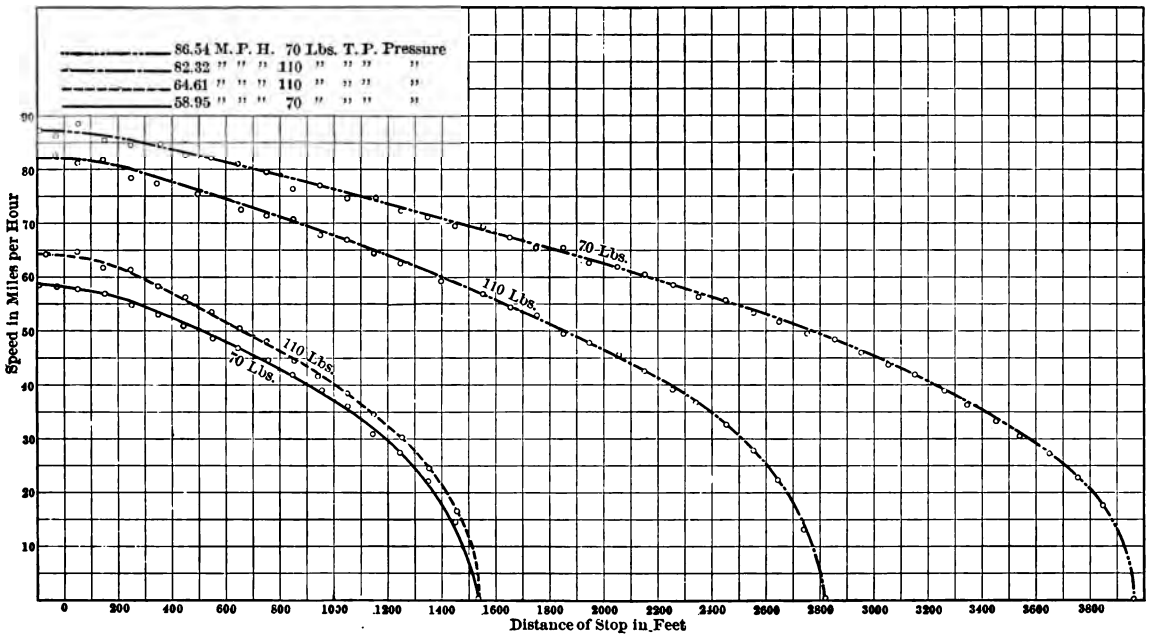

Fig. 115 Curve of Velocities from Moment of Application of Brakes, for Train of Engine, Three Coaches, and Chair Car.

is applied till the train stops, for various speeds from 56 to 80 miles per hour for a train consisting of engine, 6 coaches and 1 chair car. The trainpipe pressure is noted in each curve, and it will be remembered that 110 pounds indicates the high-speed brake, while 70 pounds indicated the quick-action brake. Vertical distances represent the speed in miles per hour and horizontal distances show the distance in feet traveled from the point where the brake was applied. Thus it will be seen that with an initial speed of 80 miles per hour, after the train went 2,000 feet from the point where the brake was applied, the speed was reduced in the case of the high-speed brake to 30 miles per hour, whereas with the quick-action brake it was reduced to 45 miles per hour. The difference in the length of stops, 22½ per cent., is also shown.

Fig. 114 shows the velocity curves for a train of engine and 6 coaches without the chair car. Fig. 115 is the same for a train consisting of engine, 3 coaches, and 1 chair car, and Fig. 116 for a train consisting of engine and 3 coaches. Fig. 117 shows same for engine alone.

Fig. 118 shows a comparison of the lengths of stops, with emergency application of the brake, of the high-speed brake and the quick-action brake for the locomotive alone. In this diagram vertical dimensions show the speed at which the locomotive was moving when the brake was applied and horizontal distances represent the number of feet traveled before it came to a stop. The full line represents the stop with quick-action apparatus, and the dotted line with high-speed attachment and pressure. It is well to note that the difference in lengths of stop between these two curves for any given speed is the horizontal distance between them at the vertical height indicated for that speed, as given at the left of the diagram. For instance; at 80 miles per hour, the length of stop for the high-speed brake is shown as 3,500 feet; for the quick-action brake, 4,200 feet. For that speed, therefore, the high-speed brake made a stop of 700 feet, or over ⅛ of a mile less than the quick-action brake, so that the high-speed stop was 83 per cent. of the

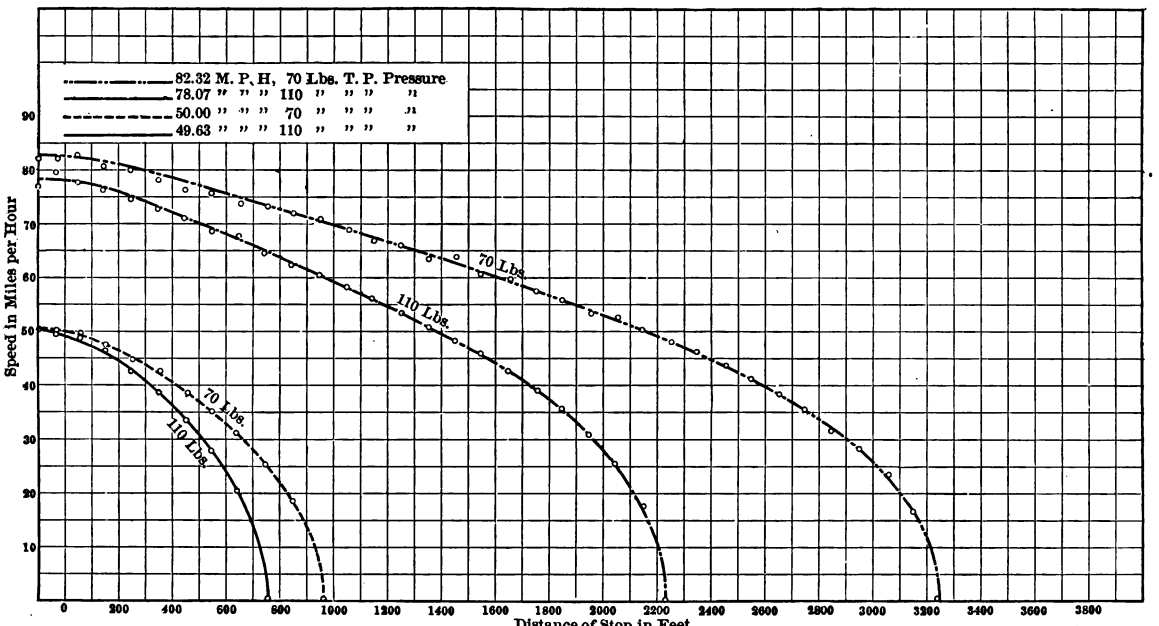

Fig. 116 Curve of Velocities from Moment of Application of Brakes, for Train of Engine and Three Coaches.

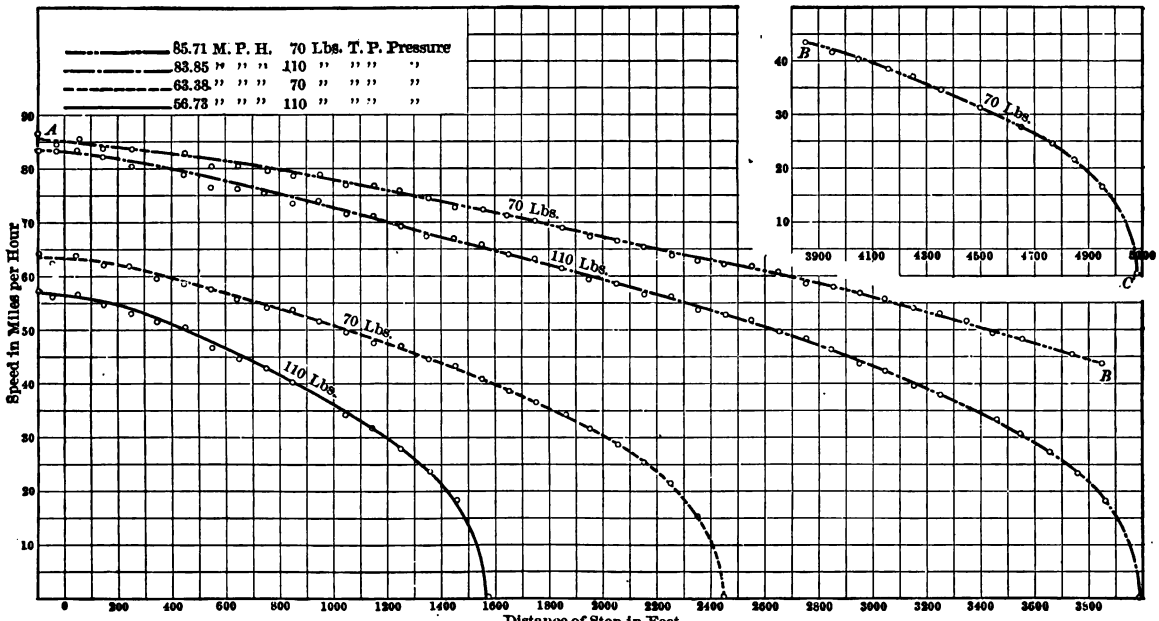

Fig. 117 Curve of Velocities from Moment of Application of Brakes, for Engine Alone.

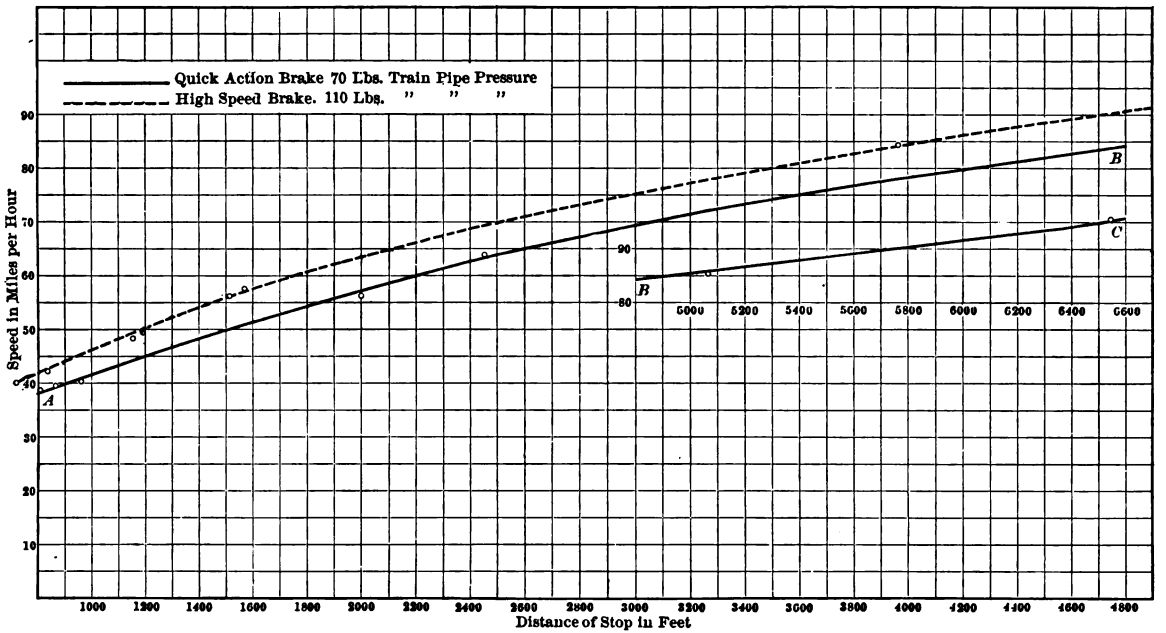

Fig. 118 Comparison of Lengths of Stops after Emergency Application of the Brakes for Various Initial Speeds of Engine Alone.

quick-action stop, and the distance saved by the use of the high-speed brake was 20 per cent. At the higher speeds the length of stop with quick-action was longer than the length and scale of this diagram will permit to be placed on it, so the curve has been broken at B and continued below from B to C.

Fig. 119 is the same diagram as Fig. 118, only in reference to a train of engine, 6 coaches, and 1 chair car. Fig. 120 is for a train of engine, 3 coaches and 1 chair car. Fig. 121 shows comparison of the stops made by trains of different make-up with the quick-action brake, using 70 lbs. trainpipe pressure; and Fig. 122 shows a similar comparison with the high-speed brake using 110 lbs. trainpipe pressure.

Comments.

From the curves it is apparent that the coaches were more effectively braked than the engine, tender, or the chair car.

In this connection special attention is called to the "Parting Test" runs recorded as Nos. 6 and 7, Figs. 121 and 122. In these two runs the train consisted of the 6 coaches and the locomotive. Just before the application of the brake the tender was uncoupled, so that each section could be stopped at different points. The results obtained were that on the run carrying 70 lbs. trainpipe pressure at a speed of 67.8 miles per hour, the 6 cars in the train ran 1,416 ft., while the engine and tender ran 2,828 ft., almost twice as far. In the run with 110 lbs. trainpipe pressure and an initial speed of 67.7 miles per hour, the coaches stopped in 1,021 ft., while the engine and tender ran 2,360 ft., or more than twice as far.

It must be borne in mind that this proportion of length of stop between engine and train does not at all represent standard conditions; it chanced that this engine and tender selected had a braking power of only 48 per cent., due to the fact that the brakes had not been properly maintained. The usual practice is to brake the locomotive to 75 per cent. and the passenger coaches to about 90 per cent. of their light weight, so that in any case the braking power of the locomotive would only be about 83 per cent. of that of the passenger coach. Consequently

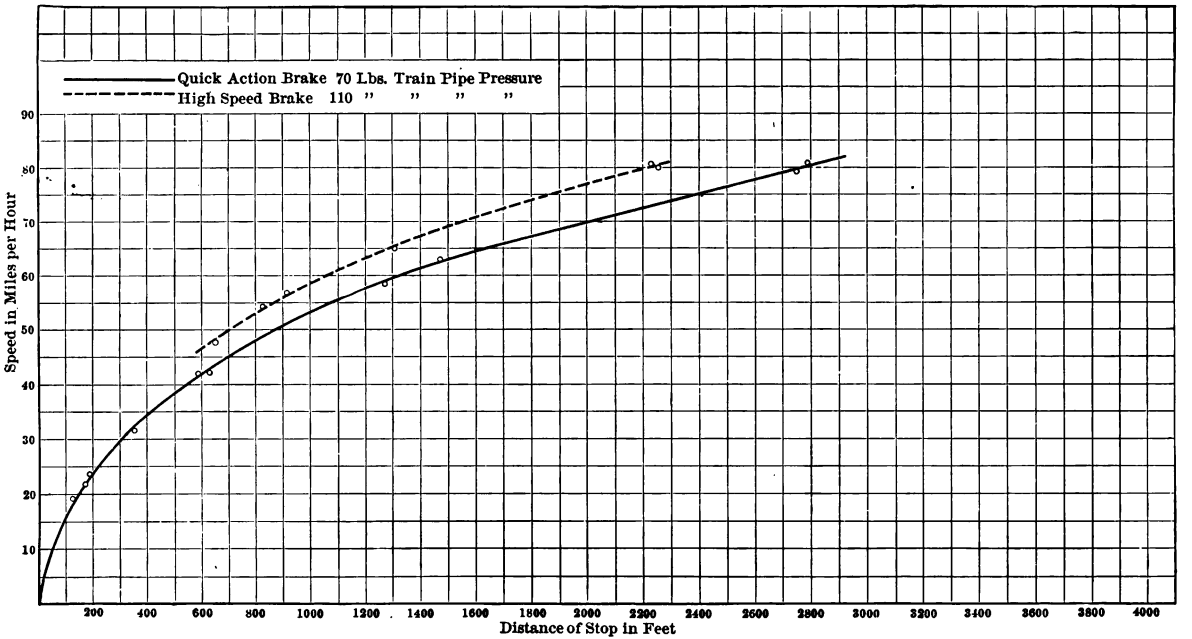

Fig. 119 Comparison of Lengths of Stops after Emergency Application of Brakes for Various Initial Speeds with Train of Engine, Six Coaches, and Chair Car.

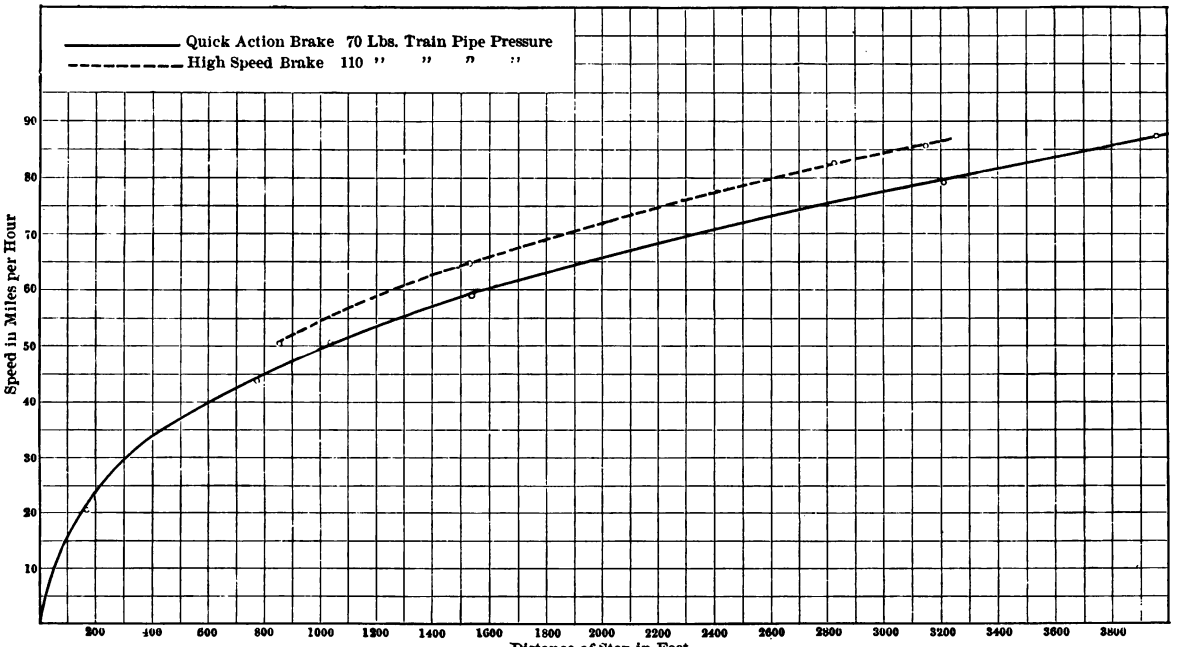

Fig. 120 Comparison of Lengths of Stops after Emergency Application of Brakes for Various Initial Speeds with Train of Engine, Three Coaches, and Chair Car.

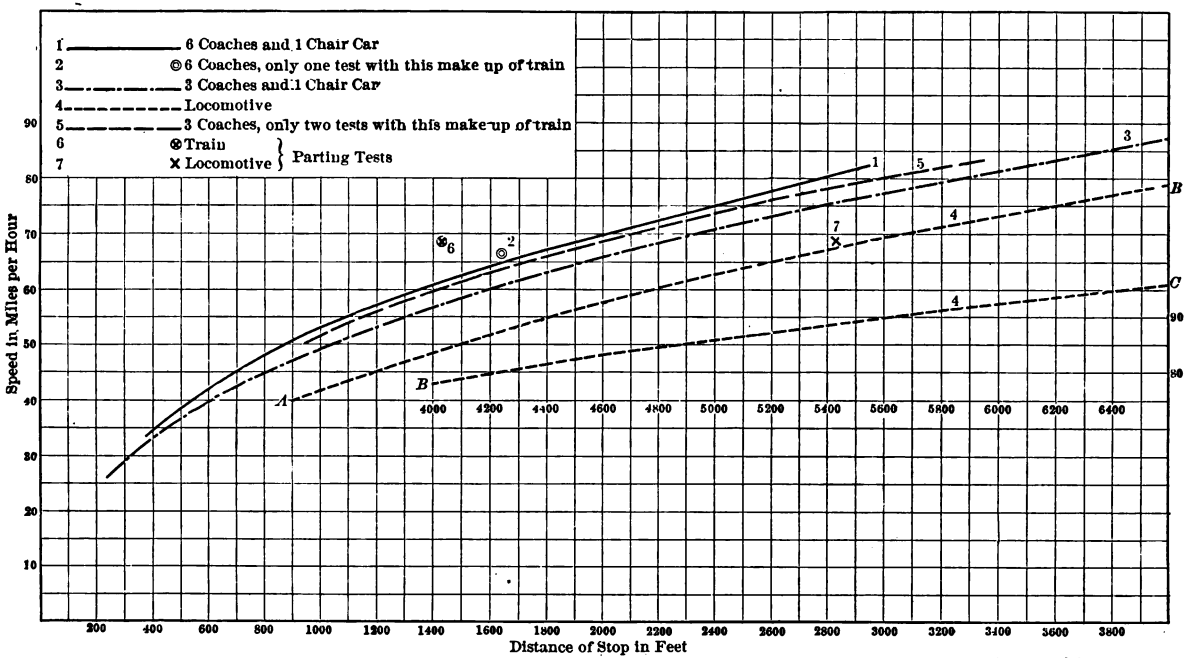

Fig. 121 Comparison of Lengths of Stops after Emergency Application of Brakes, with Trains of Different Make Up, Equipped with the Quick Action Brake, Seventy Pounds Train Pipe Pressure.

TABLE XLVII.— ACTUAL AND CALCULATED LENGTHS OF STOP, WITH VARIOUS MAKE-UPS OF TRAIN.

Make Up of Train.	Actual Speed, Miles per Hour.		Actual Brake-pipe Pressure.		Actual Length of Stop in Feet.		Speed for Calculated Stop. M. P. H.	Brake-pipe Pressure for Calculated Stop, Lbs.		Length of Calculated Stop.	
	High Speed.	Quick Action.	High Speed.	Quick Action.	High Speed.	Quick Action.		High Speed.	Quick Action.	High Speed.	Quick Action
Engine alone	42.19	40.08	109.25	69.75	825.66	950.83	45	110	70	920	1,180
do. do.	49.67	56.38	107.25	70.75	1,189.33	2,004.50	50	110	70	1,170	1,480
do. do.	56.89	56.38	107.25	70.75	1,569.92	2,004.50	60	110	70	1,760	2,210
do. do.	. .	. .	. . .	. .	. . . .	. . . .	70	110	70	2,530	3,065
do. do.	83.98	85.71	109.25	68.75	3,986.00	5,074.66	80	110	70	3,500	4,200
Engine and 3 coaches	50.24	50.21	109.75	70.13	760.08	958.66	50	110	70	753	951
do. do.	78.20	82.04	109.25	69.75	2,234.75	3,242.50	80	110	70	2,340	3,085
Engine, 3 coaches, and 1 chair car	. .	43.72	. . .	69.75	. . . .	782.83	45	110	70	670	810
do. do. do.	50.66	50.43	109.50	70.25	855.92	1,023.92	50	110	70	830	1,030
do. do. do.	64.64	58.80	110.25	70.12	1,537.17	1,529.50	60	110	70	1,275	1,615
do. do. do.	. .	. .	. . .	. .	. . . .	. . . .	70	110	70	1,880	2,340
do. do. do.	82.36	80.00	110.25	70.00	2,816.25	3,203.25	80	110	70	2,610	3,205
Engine and 6 coaches	65.45	65.12	110.00	69.75	1,265.00	1,629.50	65	110	70	1,245	1,623
Engine, 6 coaches, and 1 chair car	47.66	42.07	111.38	69.25	641.50	622.75	45	110	70	560	710
do. do. do.	53.86	. .	197.75	. .	824.00	. . . .	50	110	70	705	880
do. do. do.	64.95	62.00	109.75	70.00	1,306.58	1,472.75	60	110	70	1,060	1,360
do. do. do.	. .	. .	. . .	. .	. . . .	. . . .	70	110	70	1,560	2,020
do. do. do.	80.49	79.47	110.00	69.75	2,231.08	2,741.82	80	110	70	2,240	2,780

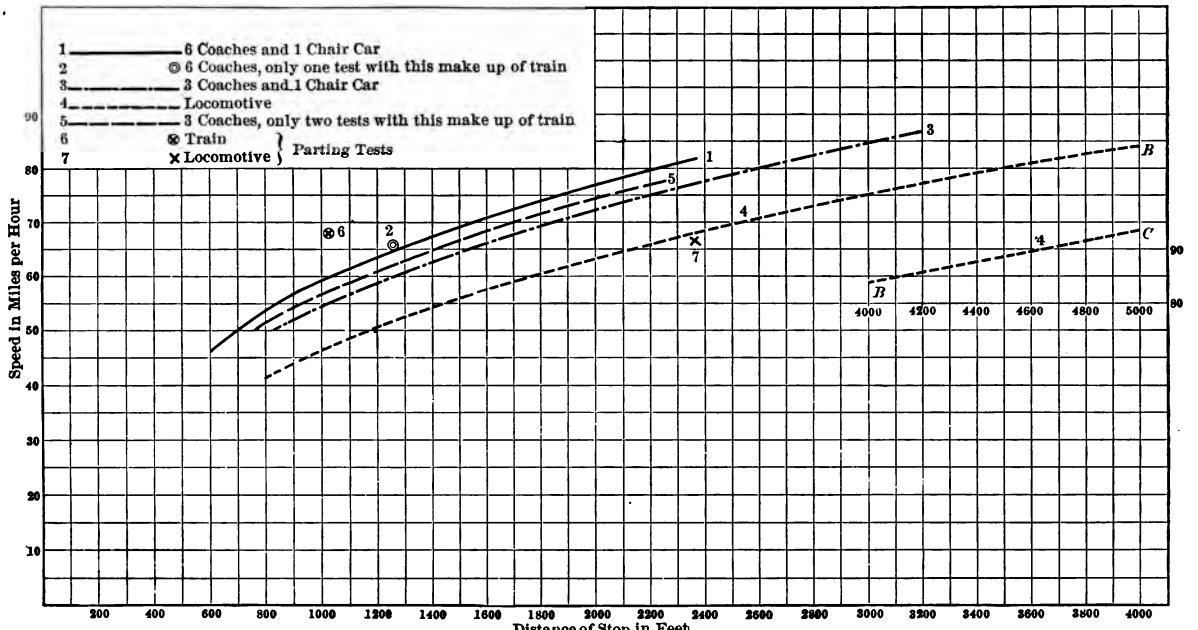

Fig. 122 Comparison of Lengths of Stops after Emergency Application of Brakes with Trains of Different Make Up, Equipped with the High Speed Brake, 110 Pounds Train Pipe Pressure.

under the very best conditions in such parting tests as above described, the locomotive would show at least a 20 per cent. longer stop than the train.

Wheel Skidding.

The weather conditions were, in general, fair and the rail good. Even with the rail partly wet, no sliding of any consequence could be attributed to it. The programme did not provide for the use of sand during the stops, but through inadvertance the rail was sanded fully during one stop at 50.1 miles per hour, and another at 60.1 miles per hour. The difference in the length of the stop with and without sand was inappreciable, and no proof exists that the sand was markedly beneficial.

Very little sliding was experienced in the earlier part of the trials, although the brake pressure on the coaches during the first part of the application was 143 per cent. of the weight on the rail. As the tests progressed, the sliding on some of the cars increased slightly, although apparently the conditions of the stop did not change, but the wheels which had once slid seemed to be more liable to do so again.

Results.

The general results given in tables XLVII. and XLVIII. show the length of stop in feet for both high-speed and quick-action brakes for various speeds from 45 to 80 miles per hour, and for trains of different make-up. Table XLVII. gives the results as actually recorded and also as reduced to uniform speeds by the methods of calculation usually employed. The second table gives the percentage relation of the high-speed stop to the quick-action; also the percentage of distance saved by the high-speed brake. In this last table the trains are placed in order of their stopping efficiency for each speed, beginning with the lowest, the speed being given in column 1, and the make-up of the train in column 2. The length of stop in feet with the high-speed brake is given in column 3, and with the quick-action brake in column 4. Column 5 shows what percentage the high-speed stop was of the quick-action stop, the latter being taken as

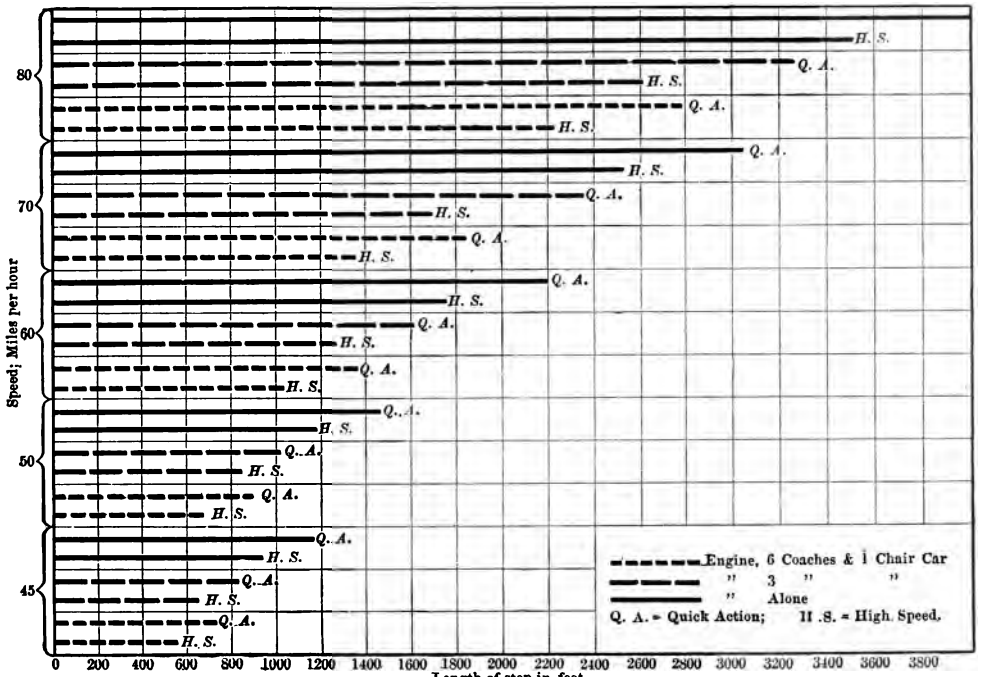

Fig. 123 **Graphical Representation of Results.**

unity. Column 6 gives the percentage saved by the use of the high-speed brake, being the difference between the two stops divided by the high-speed stop.

The results given in these tables are plotted graphically in Fig. 123. The horizontal distances represent the length of stop in feet, and the various make-ups of train are grouped together for each speed as given at the left of the diagram. The make-up of train is shown by different lines as indicated, and the kind of brake apparatus used is shown for

TABLE XLVIII. — TRAINS PLACED IN ORDER OF THEIR STOPPING EFFICIENCY, RELATIVE LENGTH OF STOP IN FEET, AND PERCENTAGE OF SAME.

Quick Action Taken as Unity.

Speed in M. P. H.	Make-up of Train.	Length of Stop in Feet.		Per Cent. of Stop.	Per Cent. Saved by High-Speed Brake.
		High-Speed Brake.	Quick-Action Brake.		
45	Engine, 6 coaches and chair car	560	710	78.8	26.8
45	do. 3 do. do. do.	670	810	82.7	20.9
45	do. alone	920	1,180	77.9	28.3
50	do. 6 coaches and chair car	705	880	80.1	24.8
50	do. 3 do. do. do.	830	1,030	80.5	24.1
50	do. alone	1,170	1,480	79.0	26.5
60	do. 6 coaches and chair car	1,060	1,360	78.0	28.3
60	do. 3 do. do. do.	1,275	1,615	78.9	26.7
60	do. alone	1,760	2,210	79.6	25.6
70	do. 6 coaches and chair car	1,560	2,020	77.1	29.5
70	do. 3 do. do. do.	1,880	2,340	80.3	24.5
70	do. alone	2,530	3,065	82.5	21.1
80	do. 6 coaches and chair car	2,240	2,780	80.7	24.1
80	do. 3 do. do. do.	2,610	3,250	80.3	24.5
80	do. alone	3,500	4,200	83.3	20.0

each train. This figure shows at a glance the constant superiority of the high-speed brake, as well as the rapid increase of distance necessary to stop a train as the speed increases. It also shows that the superiority of the high-speed brake is almost exactly the same proportionately for all speeds.

Air Brake Tests

THE ABSECON TESTS

Conclusions.

With an emergency application, trains equipped with the high-speed brake stopped in about 26 per cent. less distance than trains with the quick-action brake employing a trainpipe pressure of but 70 lbs. The emergency feature was available after the brake had been applied in service in response to a considerable reduction of trainpipe pressure.

In service application, aside from obtaining a more prompt response of the brakes, owing to the quicker flow of air due to the higher pressure, the high-speed brake was practically the same as the quick-action brake, with the further advantage that the high pressure gave an available reserve which made several full service applications possible without recharging. This feature on long grades is of the greatest value.

With the short trains less effective braking occurred, because of the average braking power being less on account of the engine and tender forming such a large per cent. of the total weight, and being braked at a less percentage than the cars. Consequently, the shorter a train the greater the necessity for the use of the high-speed equipment, and the most complete and efficient brakes on the locomotive and tender.

A truck brake should be on all passenger engines, and on those hauling short trains it is indispensable. It is also necessary to have the efficiency of the driver and tender brakes kept commensurate with modern practice.

The diagrams show very clearly the great increase of distance required to stop as the speed increases.

The gain in efficiency of the high-speed, as compared with the quick-action brake, was practically constant at the different speeds at which comparative tests were made.

ATSION TESTS.

In May and June, 1903, some comparative high-speed brake tests were made at the instance and under the supervision of the Central Railroad of New Jersey at Atsion Station.

The purpose of these tests was to compare the Westinghouse high-speed brake equipment with a new and improved arrangement of the New York brake apparatus. This arrangement of the New York air brake apparatus consisted of special triple valves, in connection with which ordinary pop valves were used, which were set to close at 70 lbs. pressure per square inch ; the brake on the cars being arranged for 60 lbs. pressure, to represent 90 per cent. braking power. The same train was also equipped with Westinghouse special triple valves and high-speed reducing valves set to close at 60 lbs. pressure per square inch ; the closing pressure being the same as that for which the car leverages were arranged. The trainpipe pressure in both systems were supposed to be 110 lbs.

These tests were run under almost precisely the same arrangement of apparatus and supervision as those of the Absecon test just described. A substantial cabin for housing the instruments was built at a point selected with reference to the attainment of the highest possible speed, and at a distance of 40 ft. from the track, to avoid vibration, which might otherwise have affected the very delicate speed-recording devices employed. These devices included a chronograph, a clock for beating seconds, and the usual electrically operated mechanism for indicating the exact moment when the circuit breakers, erected for over a mile along the track, were opened and closed by a "sweeper" on the engine provided for that purpose. The record thus obtained showed the exact speed of the train at the instant the brakes were applied, the rate of retardation during the 100 ft. following the application, and the length of stop in both seconds and feet. During the tests representatives of the railroad company and of both air brake companies were present and all figures were carefully checked and rechecked by all parties concerned.

TABLE XLIX.— COMPARATIVE TESTS OF HIGH-SPEED BRAKE

On the Central Railroad of New Jersey, Near Atsion, New Jersey, May and June, 1903.

Kind of Brake.	No. of Cars.	Actual Speed, M. P. H.	Actual Brake-pipe Pressure, Lbs.	Actual Length of Stop, Feet.	Speed for Calculated Stop, M. P. H.	Brake-pipe Pressure for Calculated Stop, Lbs.	Length of Calculated Stop, Feet.	Average Length of Calculated Stop, Feet.
Westinghouse	3	78.60	110.3	2053.00	80	110	2133.44	
Westinghouse	3	79.64	110.5	2108.00	80	110	2137.09	2099.96
Westinghouse	3	77.92	109.7	1929.75	80	110	2029.37	
New York	3	77.58	109.5	2152.25	80	110	2270.96	
New York	3	78.60	109.6	2255.16	80	110	2334.92	2308.19
New York	3	80.35	109.5	2340.75	80	110	2318.71	
Westinghouse	3	70.03	109.2	1595.58	70	110	1579.23	
Westinghouse	3	70.86	109.6	1572.75	70	110	1529.99	1554.61
New York	3	69.23	109.3	1540.58	70	110	1573.19	
New York	3	68.70	109.5	1537.08	70	110	1594.23	1582.68
New York	3	69.23	109.3	1548.00	70	110	1580.63	
Westinghouse	6	69.23	109.6	1262.91	70	110	1286.31	
Westinghouse	6	70.86	109.3	1424.58	70	110	1381.06	1333.68
New York	6	70.31	110.0	1566.16	70	110	1552.38	
New York	6	70.03	109.5	1600.33	70	110	1597.60	1571.34
New York	6	70.03	109.6	1566.50	70	110	1564.06	
Westinghouse	6	59.80	109.4	974.75	60	110	976.16	
Westinghouse	6	60.20	109.4	995.00	60	110	982.82	982.30
Westinghouse	6	58.82	109.4	954.83	60	110	987.92	
New York	6	59.60	109.1	1014.66	60	110	1026.19	
New York	6	59.21	109.3	968.41	60	110	992.57	1015.07
New York	6	58.82	109.0	989.25	60	110	1026.45	
Westinghouse	6	51.28	109.0	656.75	50	110	618.50	
Westinghouse	6	51.13	109.1	613.25	50	110	582.03	602.16
Westinghouse	6	50.84	109.1	631.83	50	110	605.95	
New York	6	50.56	109.3	706.08	50	110	688.98	
New York	6	49.18	109.4	650.08	50	110	670.90	670.95
New York	6	50.42	110.0	664.00	50	110	652.98	
Westinghouse	3	79.30	70.16	2804.66	80	70	2859.76	
Westinghouse	3	78.26	71.16	2660.41	80	70	2817.97	2838.86
Westinghouse	3	70.87	71.10	2061.16	70	70	2036.90	
Westinghouse	3	69.50	69.70	2055.00	70	70	2078.53	2057.71

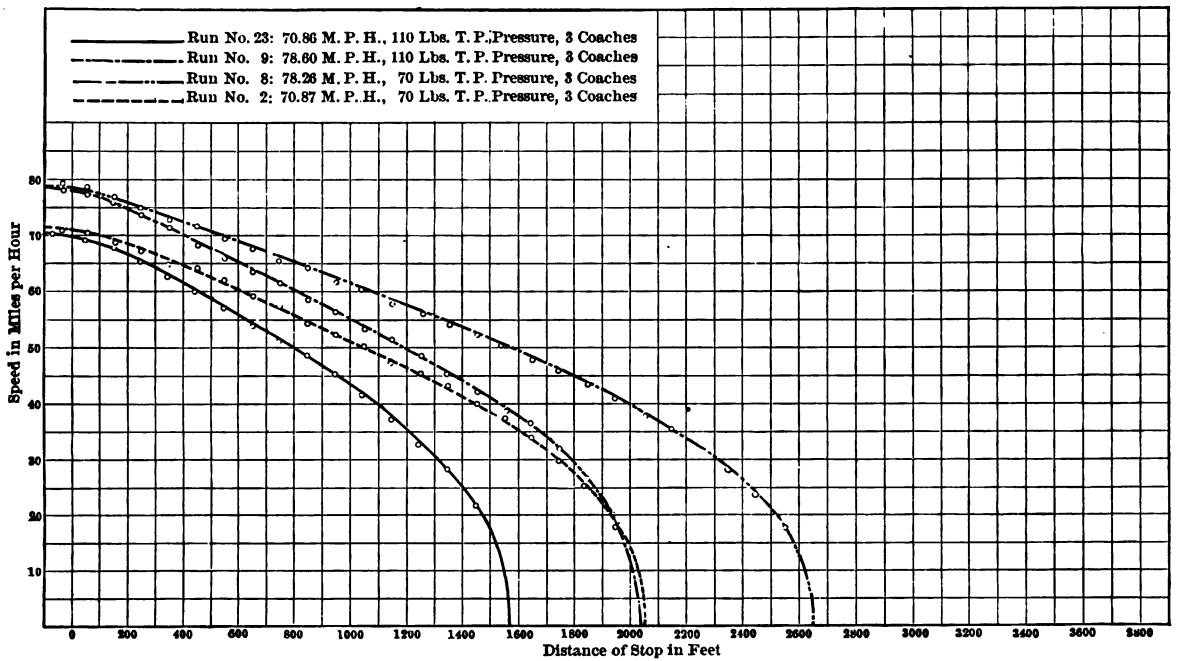

Fig. 125 Curve of Velocities from Moment of Emergency Application of the Brakes for Train of Engine and Three Coaches.

TABLE L.— TESTS OF HIGH-SPEED BRAKE

On the Central Railroad of New Jersey, Near Atsion, New Jersey, May and June, 1903; Train being Equipped with the Westinghouse Air Brake Company's Standard Valves.

No. of Cars.	Actual Speed, M. P. H.	Actual Brake-pipe Pressure, Lbs.	Actual Length of Stop, Feet.	Speed for Calculated Stop, M. P. H.	Brake-pipe Pressure for Calculated Stop, Lbs.	Length of Calculated Stop, Feet.	Average Length of Calculated Stop, Feet.
6	70.03	109.75	1527.25	70	110	1522.88	
6	69.76	109.80	1533.66	70	110	1541.75	1509.55
6	70.31	111.80	1456.08	70	110	1464.04	
6	61.43	109.66	1029.50	60	110	979.44	
6	58.44	110.25	935.75	60	110	988.34	986.24
6	59.60	110.50	973.92	60	110	990.95	
6	51.42	110.25	670.41	50	110	635.15	
6	49.58	110.30	622.00	50	110	634.08	634.61
3	76.27	100.03	1945.50	80	110	1974.37	
6	70.03	70.08	1972.58	70	70	1972.73	
6	70.58	70.00	1893.50	70	70	1862.50	1899.42
6	70.31	70.00	1879.58	70	70	1863.04	

the moment of application, and the vertical represent the speed in miles per hour. The 8 runs are grouped in 4 pairs, approximating 50, 60, 70, and 80 miles per hour at the moment of application. Each pair is made up of a New York and Westinghouse run. The actual speeds of the train at the moment of application are given in the table in Fig. 124, and refer to each run as marked upon the curves.

As mentioned above, the Westinghouse tests were made to include a series of stops with the ordinary quick-action brake, in order to compare them with the other stops made during the tests. These are shown in Figs. Nos. 125 and 126, and will be of special interest in comparison with similar tests made in the Absecon tests previously described.*

* It will be noted that the Absecon tests were made to determine the relative efficiency of the quick-action and high-speed brake apparatus under similar conditions, without regard to whether these conditions were the best obtainable. In the Atsion tests the primary object in fitting up the trains was to have all apparatus regulated to give its maximum efficiency; consequently, the results in the latter tests show more nearly what can be obtained if the apparatus is properly and carefully maintained.

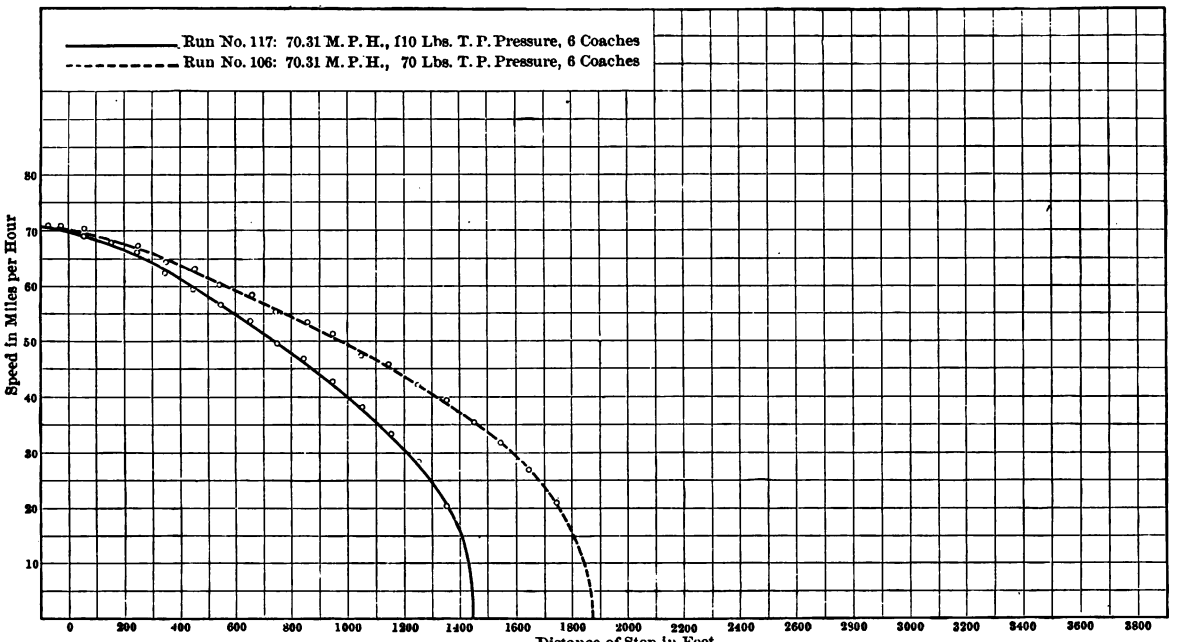

Fig. 126 Curve of Velocities from Moment of Emergency Application of the Brakes for Train of Engine and Six Coaches.

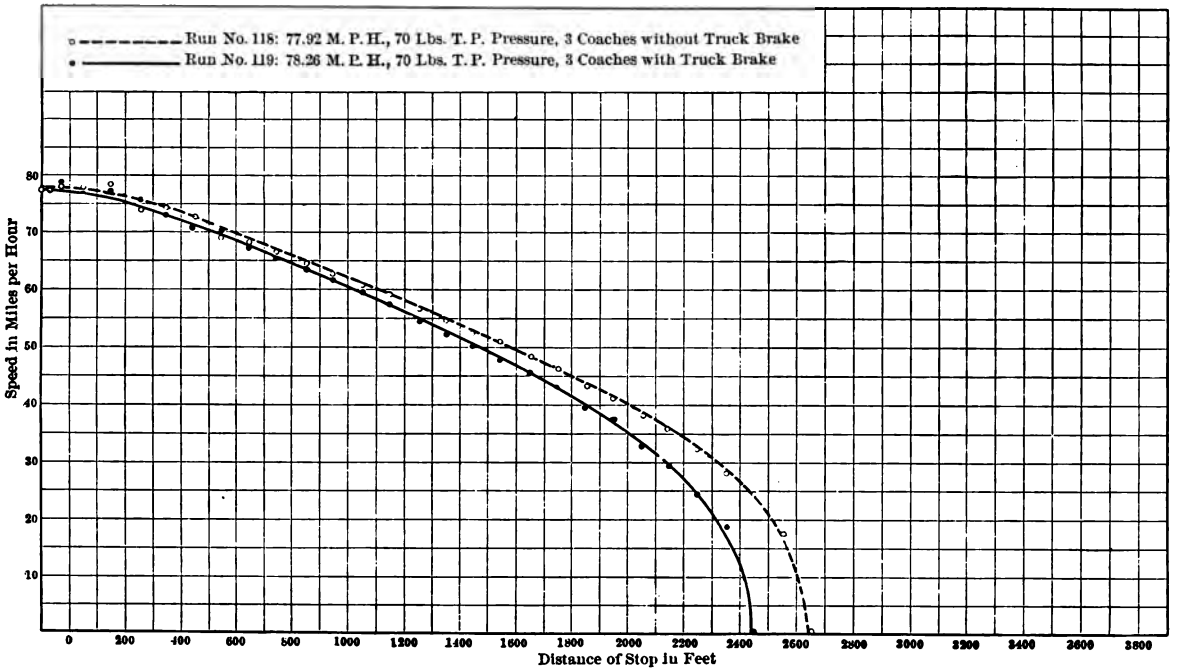

Fig. 127 Curve of Velocities from Moment of Emergency Application of the Brakes for Train of Engine and Three Cars, Showing Difference in Stop, with and without the Engine Truck Brake.

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Fig. 125 shows the change in velocities of the three coach train from the moment of application for stops of 70 and 80 miles per hour. It will be noted that the length of high-speed brake stops for 80 miles per hour is shorter than that of the quick-action stop for 70 miles per hour. Fig. 126 contains curves similar to those of Fig. 125 for train of engine and six coaches for initial speed of 70 miles per hour.

Fig. 127 is of especial interest as indicating the effect upon the length of stop of the engine truck brake. Runs No. 118 and 119 were made with a train of engine and three coaches, the first without the truck brake, and the second with the same. The initial speed was 78 miles per hour, and the length of stop without the truck brake was 2,640 ft., whereas, with the truck brake, under same conditions, the stop was reduced to 2,440 ft., being a saving of exactly 200 ft., which is 7.7 per cent. decrease. This is a graphical statement of actual stops, and leaves no room for doubt as to the advisability of having engine truck brakes.

Indicator Diagrams.
High Speed Brake Applications.

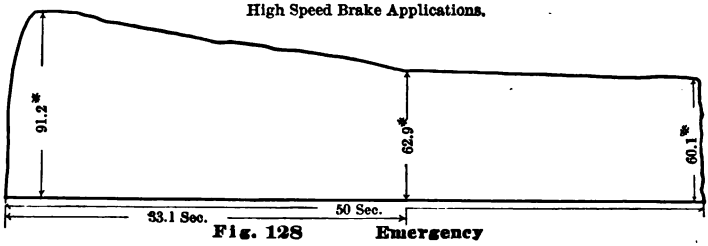

Fig. 128 **Emergency**

The nature of these tests could not develop one of the most valuable features of the high-speed brake in service, namely, the greatly increased ability to make several full applications of the brakes without recharging. This feature was developed during subsequent tests, as well as the fact that an emergency application could be produced after a considerably larger service reduction had been made than is possible with the quick-action brake. This is well shown by the cuts in Figures 128, 129, and 130, which are reproductions of indicator diagrams taken from cylinders when in use with the high-speed apparatus. The horizontal dimensions of these diagrams represent the time

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in seconds and the vertical dimensions pressure in pounds per square inch.

Fig. 128 shows an emergency application on the high-speed brake. The cylinder and reservoir became equalized at a high pressure and the reduction was slowly effected until it reached the amount for which the reducing valve was set. Fig. 129

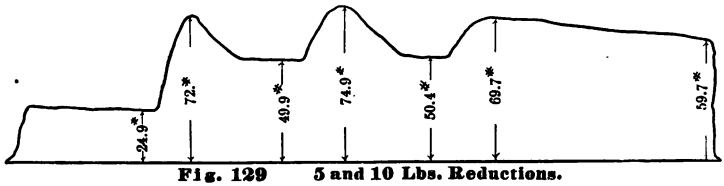


Fig. 129 5 and 10 Lbs. Reductions.

shows several successive service reductions in one application, and Fig. 130 shows a service application of 18 lbs. reduction followed by an emergency.

From table No. XLIX. it will be seen that the average length of stop of the high-speed apparatus was shorter than that of the New York

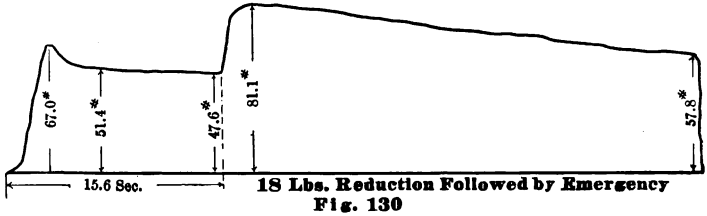
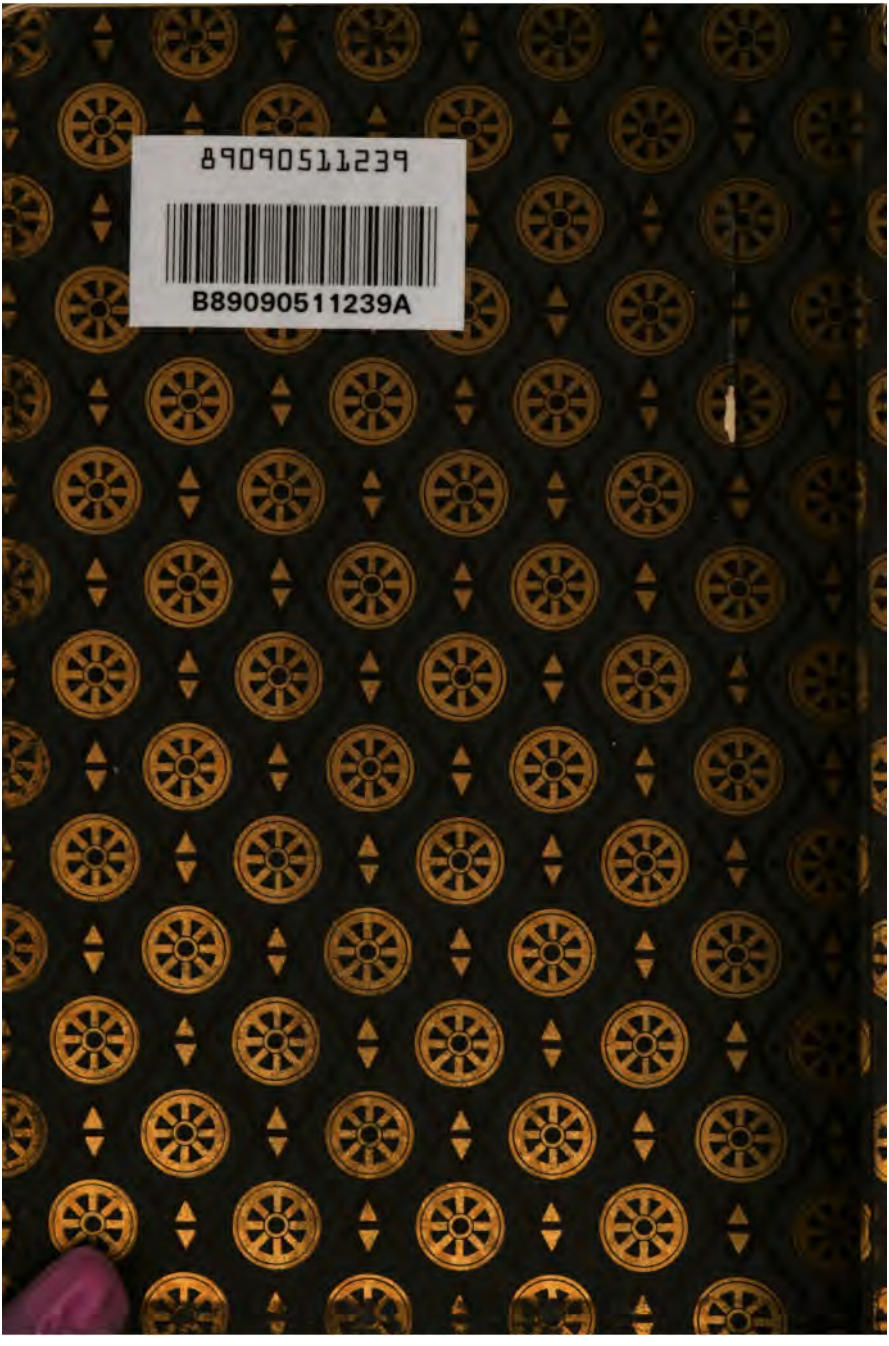


Fig. 130

arrangement by from 11½ per cent. at 50 miles per hour to 10 per cent. at 80 miles per hour; while for 70 miles per hour and a 6-coach train it was 18 per cent. shorter.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